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# Effect of γ-irradiation on respiration rate and ethylene levels of mutant lines to enhance shelf life of papaya var. arka prabhath (*Carica papaya L.*)

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**Abstract**

The Papaya *Arka Prabhath* is an advanced generation gynodioecious variety released by ICAR-IIHR. The fruits were observed for 10 days weight, ethylene production and the $CO_2$ rate which were found to be varying each day. The rate of respiration of fresh produce is temperature dependant and it was controlled by many enzymes. Reducing the rate of respiration is an important consideration in extending the postharvest life of a fruit and optimizing postharvest quality. Some of the lines were selected for shelf life studies based on qualitative and quantitative traits like vigour, dwarf nature, quality, early flowering, resistant to Papaya Ring Spot Virus, hermaphroditic types, type of fruit and firmness of the fruits. Total 11 promising mutants are identified in $M_2$ population and one among 11 is $R_5P_6$ mutant which showed significant variation in fruit weight it ranged from 1695.57g to 1580.56g. The respiration rate ranged from 51.84 mg $CO_2$ kg/h to 88.86 mg $CO_2$ kg/h. However, 115.01g decrease in fruit weight and an increase of 37.02 mg $CO_2$ kg/h was observed during 10 days and inverse relation between physiological loss of weight and respiration rate was observed. During respiration, there was a significant increase in volume of water consumed from 7747.55 ml to 7897.85 ml for 10 days.

**Keywords:** papaya, PRSV, gynodioecious, respiration, ethylene, carbon dioxide

## Introduction

The woody plant Papaya is gynodioecious (*Carica papaya* L.) belongs to the family Caricaceae, is one of the most economically important fruit crops of the tropical and subtropical regions of the world (Ramesh, *et al*., 2019) and trade amounted nearly 200.000 million dollar by 2009 (Evans and Ballen, 2012).

It has been successfully cultivated in India, USA, Brazil, Mexico, Nigeria, Jamaica, Indonesia, China, Taiwan, Peru, Thailand and Philippines. India stands first in production of papaya in the world followed by Brazil, Indonesia, Mexico and Ethiopia. The area under papaya in India is estimated at 1,46,000 ha and production at 65,08,000 metric tons (NHB, 2019). In India, it is commercially cultivated in Andhra Pradesh, Gujarat, Maharashtra, Karnataka, West Bengal, Assam, Odisha, Madhya Pradesh, Manipur, Tamil Nadu, Bihar and to a certain extent in Kerala.

Carica papaya is an important species in the family and it is the only member of the genus after its rehabilitation from the Vasconcella group which was considered part of the genus Carica, until the year 2000. The Caricaceae family originated in Africa where two extant species occur. The dispersal to Central America from Africa occurred ca. 35 million years ago (MYA), possibly by floating vegetation carried by ocean currents (Badillo, 2000).

Papaya fruit being climacteric and perishable in nature have low shelf life hence harvest and postharvest losses are reported together 7.36 percent wherein, the farm operation, storage, and transportation losses together account for 5.06, 2.28 and 1.13 percent, respectively. The major constraint that hinders the expansion of export of papaya fruit is short storage life, susceptibility to postharvest diseases, high shipment cost and pesticide residues. Postharvest fruit decay is a major constraint in post-harvest handling causing decreases in both quantity and quality of the product. Major postharvest losses are due to pathogenic microorganisms, which can infect fruit through wounds or latent infections during the pre-harvest period. Among the postharvest pathogens, fungal diseases are one of the major causes of fruit decay as they account for 80-90 % of all losses. Papaya ripens rapidly after harvesting, through elevation of ethylene and increased respiratory rate. Skin yellowing, fruit softening, respiratory rate, and ethylene production were monitored after the fruit was harvested at the color break stage. Mutation breeding is one of the approaches to create variability through novel recombinations using both chemical and physical mutagens to develop mutant lines to enhance shelf life by down regulating ACC Synthase and ACC Oxidase gene through TILLING ( Reverse genetics) technology (Ramesh, *et al*., 2019).

*Gamma irradiation* has been demonstrated to be an effective technique for insect disinfestation and shelf-life extension of various tropical and subtropical fruits, such as, papaya, mango, and banana. Recent studies have confirmed that softening of papaya is generally retarded growth by irradiation, and the level of respiration is reduced by low irradiation doses of 0.50 to 0.95 kGy. There is considerable contradictory literature and it has been suggested that maturity at the time of irradiation is a major cause (Granier, *et al.*, 2015).

The objectives of this research were to evaluate the effect of γ- irradiation on respiration rate and Ethylene levels of mutant lines to enhance shelf life of papaya Var. Arka Prabhath (*Carica papaya L.*).

## Materials and Methods

The present investigation on "Effect of γ- Irradiation on Respiration Rate and Ethylene
Levels of Mutant Lines to Enhance Shelf Life of Papaya Var. Arka Prabhath (*Carica papaya L.*)' was carried out at the ICAR- Indian Institute of Horticultural Research (ICAR-IIHR), Arka Prabhath is an advanced generation hybrid derivative from the cross of (Arka Surya x Tainung-1) x Local Dwarf released from ICAR- Indian Institute of Horticultural Research. It is gynodioecious in nature, with large sized fruits of 900-1200 g and smooth skin. The pulp is an attractive deep pink colour with good keeping quality and high TSS (13-14°B).

The seeds of Arka Prabhath are gamma-irradiated with the 50 Gy, 100 Gy, 250 Gy 500 Gy and 750 Gy Gamma rays and sown the seeds in polyethylene bag in green house. The seedlings were planted 45 days after sowing in RCBD design and nearly 600 mutant lines are screened in $M_2$. Among which Some of the lines ($R_5P_6$,$R_{13}P_{10}$,$R_8P_{18}$, $R_3P_{14}$,$R_9P_{13}$,$R_8P_{18}$,$R_7P_{18}$,$R_{18}P_{19}$,$R_6P_8$,$R_7P_4$ and $R_4P_{16}$) were selected for shelf life studies based on qualitative and quantitative traits like vigour ($R_5P_6$ $R_{13}P_{10}$,$R_8P_{18}$,$R_3P_{14}$, $R_9P_{13}$,$R_8P_{18}$,$R_7P_{18}$,$R_{18}P_{19}$,$R_6P_8$,$R_7P_4$) dwarf nature($R_{13}P_{10}$) quality, early flowering ($R_3P_{14}$, $R_8P_{18}$, $R_7P_4$, $R_4P_{16}$, ) tolerant to Papaya Ring Spot Virus ($R_{13}P_{10}$, $R_3P_{14}$) hermaphroditic types, type of fruit and firmness of the fruits. The harvested fruits were weighed and kept for ethylene and $CO_2$ ($R_5P_6$, $R_{13}P_{10}$,$R_8P_{18}$,$R_3P_{14}$,$R_9P_{13}$,$R_8P_{18}$,$R_7P_{18}$,$R_{18}P_{19}$,$R_6P_8$,$R_7P_4$ and $R_4P_{16}$) observations for cold storage at 20° C. The respiration rate and ethylene rate for the fruits stored under both ambient temperature and cold temperature was calculated by using this formula. Fruits were enclosed in a PET jars of 10000 ml capacity and sealed airtight throughout the experiment period.

$$\text{Respiration rate, mg } Co_2\text{/kg/hr} = \frac{2 \times (\%\ CO_2) \times (\text{Volume}) \times 60}{(\text{Fruit weight kg}) \times (\text{Enclosing time (min)}) \times 100}$$

$$\text{Ethylene rate, µl } C_2H_4\text{/kg/h} = \frac{2 \times (\%\ C_2H_4) \times (\text{Volume}) \times 60}{(\text{Fruit weight kg}) \times (\text{Enclosing time (min)}) \times 100}$$

The data on morphological and fruit characters were subjected to Independent t test which compares means between two unrelated groups on the same continuous variable using SPSS statistics. A simple randomised complete block design was followed and these treatments were assigned to different families and observations on mean, standard deviation (SD), t-test and significance (2 tailed) at the probability of 0.05 were recorded

## Results and Discussion

### Shelf life studies

The present investigation on shelf life studies was carried out at post-harvest laboratory Indian Council of Agriculture Research (ICAR) Indian Institute of Horticultural Research (IIHR). The fruit were harvested from mutagenic $M_2$ population after they attained breaker stage. The yield data were recorded from all the $M_2$ populations. The fruits were observed for 10 days weight, ethylene production and the $CO_2$ rate which were found to be varying each day. (Nhat Hang and Chau. 2010) (Fig 2 and fig 3) The storage of the papaya fruits at cold temperature resulted in very low respiration rate throughout the storage. The rate of respiration of fresh produce is temperature dependent and it was controlled by ACC Synthase and ACC Oxidase. The low temperature condition was found to reduce ACC Synthase and ACC Oxidase thus lowering the rate of respiration. The rate of respiration is having inverse relation with the potential of the produce. The data (Table1 and 2) depicted that as the days advanced, the fruit weight was measured initially was more than the weight measured during the ripening stages of the fruits which explains that fruits are supposed to get lighter as the biochemical changes such as respiration involved in the fruit.

During the process of respiration, carbohydrates sucrose are broken down to their constituent parts to produce energy to run cellular processes such as respiration thus keeping the cells and organism alive. Throughout this process, oxygen is consumed and it released water, carbon dioxide, and energy. However, the cell wall of the fruits starts degrading, as the carbohydrates stored in the harvested plant portion are continually "burned" as energy to keep the fruit alive, as respiration continues, compounds that affect plant flavor, sweetness, weight, and turgor (water content) are lost therefore, reducing the rate of respiration is an important consideration in extending the postharvest life of a fruit and optimizing postharvest quality.

**Fig 1:** Fruits at breaker stage of $M_2$ mutant lines of Arka Prabhath


**Fig 2:** Fruits of control plants at ambient temperature on 5th day after harvest (a). Fruits of control Plants at ambient temperature on 10th day after harvest (b). Fruits of mutant plants at 5th day after harvest(c). Fruits of mutant plants at 10th day after harvest (d).

**Fig 3:** Fruit colour variation of $M_2$ mutant lines of Arka Prabhath

**2. Study of gamma radiation on respiration rate and Ethylene level of promising $M_2$ mutagenic lines**

**$R_5P_6$ mutant line**

The data asserted that significant variations were noticed in the physiological loss in weight of papaya fruit during the period of storage for 10 days. The significant variations were found in fruit weight which ranged from 1695.57g to 1580.56g. The respiration rate ranged from 51.84mg $CO_2$ kg/h to 88.86 mg $CO_2$ kg/h. However, 115.01g decrease in fruit weight and an increase of 37.02 mg $CO_2$ kg/h was observed during 10 days and inverse relation between physiological loss of weight and respiration rate was observed (Graph1and 4). During respiration, there was a significant increase in volume of water consumed from 7747.55 ml to 7897.85 ml for 10 days. (Table 1 and 2).

**Table 1:** Effect of gamma radiation on respiration rate ($Co_2$) of promising mutagenic $M_2$ papaya lines

| **Mutant line ($R_5P_6$)** | **1day** | **2day** | **3day** | **4day** | **5day** | **6day** | **7day** | **8day** | **9day** | **10day** |
|---|---|---|---|---|---|---|---|---|---|---|
| Fruit weight(gm) | 1693.57 | 1675.01 | 1655.05 | 1643.46 | 1632.8 | 1624.13 | 1613.5 | 1602.25 | 1590.35 | 1580.56 |
| Stage | UR | UR | QR | QR | SR | SR | SR | FR | FR | FR |
| Time(min.) | 180 | 200 | 160 | 190 | 200 | 210 | 170 | 170 | 190 | 195 |
| $C0_2$(%) | 1.70 | 1.80 | 2.00 | 2.30 | 1.90 | 2.30 | 2.40 | 2.56 | 2.62 | 2.89 |
| Volume (ml) | 7747.55 | 7772.23 | 7798.78 | 7814.19 | 7828.37 | 7839.90 | 7854.04 | 7869.00 | 7884.83 | 7897.85 |
| Respiration rate (mg $CO_2$ kg/h) | 51.84 | 50.11 | 70.68 | 69.06 | 54.65 | 63.44 | 82.46 | 88.74 | 82.04 | 88.86 |
| Mutant line($R_{13}P_{10}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 2656.97 | 2628.42 | 2591.01 | 2572.50 | 2553.60 | 2538.80 | 2522.40 | 2506.25 | 2489.36 | 2467.23 |
| Stage | UR | UR | QR | QR | QR | SR | SR | SR | FR | FR |
| Time(min.) | 180 | 200 | 210 | 175 | 165 | 200 | 180 | 190 | 185 | 175 |
| $C0_2$(%) | 1.50 | 1.70 | 2.60 | 3.00 | 1.70 | 2.20 | 2.10 | 2.10 | 2.80 | 3.00 |
| Volume (ml) | 6466.22 | 6504.20 | 6553.95 | 6578.57 | 6603.68 | 6623.39 | 6645.08 | 6666.68 | 6689.15 | 6718.58 |
| Respiration rate (mg $CO_2$ kg/h) | 24.33 | 25.24 | 37.58 | 52.60 | 31.97 | 34.43 | 36.88 | 35.28 | 48.80 | 56.01 |
| Mutant line($R_6P_{18}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 1642.19 | 1599.6 | 1589.2 | 1580.93 | 1572.11 | 1563.51 | 1550.00 | 1535.25 | 1521.20 | 1501.41 |
| Stage | UR | UR | QR | QR | QR | SR | SR | SR | FR | FR |
| Time(min.) | 180 | 180 | 200 | 195 | 175 | 180 | 168 | 175 | 180 | 175 |
| $C0_2$(%) | 1.6 | 2.5 | 2.3 | 2.1 | 2.2 | 2.1 | 2.1 | 2.6 | 2.7 | 2.9 |
| Volume (ml) | 7815.88 | 7872.53 | 7886.30 | 7897.30 | 7909.00 | 7920.50 | 7938.50 | 7958.10 | 7976.80 | 8003.10 |
| Respiration rate (mg $CO_2$ kg/h) | 50.75 | 82.02 | 68.48 | 64.55 | 75.89 | 70.92 | 76.82 | 92.41 | 94.38 | 105.99 |
| Mutant line($R_3P_{14}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 1552.8 | 1495.56 | 1484.32 | 1470.01 | 1460.2 | 1451.32 | 1444.8 | 1435.45 | 1422.2 | 1415.69 |
| Stage | UR | UR | QR | QR | QR | QR | QR | SR | SR | FR |
| Time(min.) | 180 | 180 | 180 | 180 | 200 | 200 | 210 | 210 | 190 | 190 |
| $C0_2$ (%) | 0.8 | 1.00 | 1.43 | 1.70 | 1.80 | 2.00 | 2.20 | 2.20 | 2.80 | 2.90 |
| Volume (ml) | 7934.77 | 8010.90 | 8025.8 | 8044.8 | 8057.8 | 8069.7 | 8078.3 | 8090.8 | 8108.4 | 8117.1 |
| Respiration rate (mg $CO_2$ kg/h) | 27.25 | 35.70 | 51.54 | 62.02 | 59.59 | 66.72 | 70.28 | 70.85 | 100.82 | 105.01 |
| Mutant line($R_9P_{13}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 1944.05 | 1891.4 | 1880.92 | 1870.76 | 1860.6 | 1850.96 | 1825 | 1805.36 | 1798.7 | 1770.25 |
| Stage | UR | QR | QR | QR | QR | QR | SR | SR | FR | FR |
| Time(min.) | 180 | 180 | 180 | 180 | 200 | 200 | 210 | 190 | 190 | 190 |
| $C0_2$ (%) | 2.00 | 2.20 | 2.50 | 2.30 | 2.30 | 1.60 | 2.60 | 2.80 | 3.00 | 3.10 |
| Volume (ml) | 7414.41 | 7484.43 | 7498.3 | 7511.8 | 7525.3 | 7538.2 | 7572.7 | 7598.8 | 7607.7 | 7645.5 |
| Respiration rate (mg $CO_2$ kg/h) | 50.81 | 58.03 | 66.44 | 61.56 | 55.81 | 39.09 | 61.64 | 74.43 | 80.13 | 84.55 |
| Mutant line($R_8P_{18}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 1762.5 | 1728.14 | 1719.23 | 1712.92 | 1705.7 | 1698.7 | 1670.5 | 1658.32 | 1650.25 | 1625.41 |
| Stage | UR | UR | QR | QR | QR | SR | SR | SR | FR | FR |
| Time(min.) | 180 | 180 | 180 | 180 | 200 | 200 | 190 | 190 | 185 | 185 |
| $C0_2$(%) | 0.40 | 0.9 | 1.20 | 1.60 | 1.90 | 2.10 | 2.50 | 2.10 | 2.70 | 3.30 |
| Volume (ml) | 7655.87 | 7701.57 | 7713.4 | 7721.8 | 7731.4 | 7740.7 | 7778.2 | 7794.4 | 7805.1 | 7838.2 |
| Respiration rate (mg $CO_2$ kg/h) | 11.58 | 26.73 | 35.89 | 48.08 | 51.67 | 57.41 | 73.51 | 62.33 | 82.83 | 103.22 |
| Mutant line($R_7P_{18}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 1641.14 | 1590.07 | 1564.88 | 1572.76 | 1568.2 | 1551.68 | 1542.3 | 1531.78 | 1520.00 | 1500.67 |
| Stage | UR | UR | QR | QR | QR | SR | SR | SR | FR | FR |
| Time(min.) | 180 | 180 | 200 | 200 | 190 | 190 | 180 | 180 | 200 | 200 |
| $C0_2$(%) | 1.00 | 1.50 | 1.60 | 1.80 | 2.00 | 2.20 | 2.25 | 2.30 | 2.60 | 2.80 |
| Volume (ml) | 7817.28 | 7885.20 | 7918.70 | 7908.22 | 7914.22 | 7936.26 | 7948.66 | 7962.73 | 7978.40 | 8004.10 |
| Respiration rate (mg $CO_2$ kg/h) | 31.75 | 49.59 | 48.57 | 54.30 | 63.74 | 71.06 | 77.30 | 79.70 | 81.88 | 89.60 |
| Mutant line($R_{18}P_{19}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 2094.6 | 2071.52 | 2044.51 | 2029.71 | 2016.3 | 2005.65 | 1991.4 | 1970.25 | 1950.65 | 1940.36 |
| Stage | QR | QR | QR | QR | SR | SR | SR | FR | FR | FR |
| Time(min.) | 180 | 180 | 180 | 210 | 200 | 200 | 200 | 180 | 180 | 180 |
| $C0_2$(%) | 0.40 | 1.00 | 1.20 | 1.50 | 1.70 | 1.80 | 2.50 | 2.30 | 2.90 | 5.60 |
| Volume (ml) | 7214.18 | 7244.87 | 7280.8 | 7300.4 | 7318.2 | 7332.4 | 7351.3 | 7379.5 | 7405.6 | 7419.3 |

| Respiration rate ( mg $CO_2$ kg/h) | 9.18 | 23.31 | 28.48 | 30.82 | 37.01 | 39.48 | 55.37 | 57.43 | 73.39 | 142.75 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mutant line($R_4P_{16}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 2700.25 | 2695.63 | 2685.21 | 2674.32 | 2658.5 | 2645.26 | 2635.2 | 2600.25 | 2562.35 | 2522.21 |
| Stage | UR | UR | QR | QR | QR | SR | SR | SR | FR | FR |
| Time(min.) | 200 | 200 | 190 | 190 | 180 | 180 | 190 | 190 | 200 | 200 |
| $C0_2$ (%) | 0.80 | 0.90 | 1.20 | 1.50 | 1.60 | 1.80 | 2.00 | 2.90 | 3.50 | 4.50 |
| Volume (ml) | 6408.66 | 6414.81 | 6428.6 | 6443.1 | 6464.1 | 6481.8 | 6495.1 | 6541.6 | 6592.0 | 6645.4 |
| Respiration rate (mg $CO_2$ kg/h) | 11.39 | 12.85 | 18.14 | 22.82 | 25.93 | 29.40 | 31.13 | 46.07 | 54.02 | 71.13 |

**Table 2:** Effect of gamma radiation on ethylene rate of promising mutagenic $M_2$ papaya lines

| **Mutant line($R_5P_6$)** | **1day** | **2day** | **3day** | **4day** | **5day** | **6day** | **7day** | **8day** | **9day** | **10day** |
|---|---|---|---|---|---|---|---|---|---|---|
| Fruit weight(gm) | 1693.85 | 1675.01 | 1655.05 | 1643.09 | 1632.80 | 1622.40 | 1602.22 | 1582.09 | 1567.05 | 1500.03 |
| Stage | UR | UR | QR | QR | QR | SR | SR | SR | FR | FR |
| Time(min.) | 180 | 180 | 180 | 180 | 200 | 200 | 190 | 190 | 200 | 200 |
| Ppm | 2.00 | 2.10 | 2.90 | 3.00 | 3.10 | 3.40 | 3.50 | 3.60 | 3.80 | 4.50 |
| Volume | 8306.15 | 8324.99 | 8344.95 | 8356.91 | 8367.20 | 8377.60 | 8397.78 | 8417.91 | 8432.95 | 8499.97 |
| Ethylene | 3.27 | 3.48 | 4.87 | 5.09 | 4.77 | 5.27 | 5.79 | 6.05 | 6.13 | 7.65 |
| Mutant line($R_{13}P_{10}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 2656.97 | 2645.05 | 2632.55 | 2615.32 | 2600.25 | 2585.66 | 2562.33 | 2541.81 | 2522.05 | 2502.56 |
| Stage | UR | UR | QR | QR | QR | SR | SR | FR | FR | FR |
| Time(min.) | 180 | 180 | 180 | 180 | 210 | 210 | 185 | 185 | 190 | 190 |
| Ppm | 1.00 | 1.20 | 1.50 | 2.20 | 2.80 | 3.40 | 3.70 | 3.90 | 4.20 | 4.80 |
| Volume | 7343.03 | 7354.95 | 7367.45 | 7384.68 | 7399.75 | 7414.34 | 7437.67 | 7458.19 | 7477.95 | 7497.44 |
| Ethylene | 0.92 | 1.11 | 1.40 | 2.07 | 2.28 | 2.79 | 3.48 | 3.71 | 3.93 | 4.54 |
| Mutant line($R_6P_{18}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 1642.19 | 1633.25 | 1620.21 | 1602.52 | 1581.05 | 1565.32 | 1552.02 | 1535.32 | 1522.36 | 1503.65 |
| Stage | UR | UR | QR | QR | QR | SR | SR | SR | FR | FR |
| Time(min.) | 180 | 180 | 200 | 200 | 175 | 175 | 185 | 185 | 180 | 180 |
| Ppm | 1.10 | 1.50 | 1.60 | 2.10 | 2.50 | 3.40 | 3.50 | 3.50 | 3.80 | 4.30 |
| Volume | 8357.81 | 8366.75 | 8379.79 | 8397.48 | 8418.95 | 8434.68 | 8447.98 | 8464.68 | 8477.64 | 8496.35 |
| Ethylene | 1.87 | 2.56 | 2.48 | 3.30 | 4.56 | 6.28 | 6.18 | 6.26 | 7.05 | 8.10 |
| Mutant line($R_3P_{14}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 1552.8 | 1495.56 | 1484.32 | 1470.01 | 1460.23 | 1451.32 | 1444.85 | 1435.45 | 1422.2 | 1415.69 |
| Stage | UR | UR | QR | QR | QR | SR | SR | SR | FR | FR |
| Time(min.) | 180 | 180 | 200 | 200 | 180 | 180 | 210 | 210 | 180 | 180 |
| Ppm | 1.6 | 1.8 | 2.1 | 2.7 | 3.5 | 3.8 | 3.9 | 3.9 | 3.99 | 4.1 |
| Volume | 8447.20 | 8504.44 | 8515.68 | 8529.99 | 8539.77 | 8548.68 | 8555.15 | 8564.55 | 8577.80 | 8584.31 |
| Ethylene | 2.90 | 3.41 | 4.02 | 5.22 | 6.82 | 7.46 | 7.70 | 7.76 | 8.02 | 8.29 |
| Mutant line($R_9P_{13}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 1944.05 | 1891.4 | 1880.92 | 1870.76 | 1860.62 | 1850.96 | 1825 | 1805.36 | 1798.7 | 1770.25 |
| Stage | UR | UR | QR | QR | QR | SR | SR | SR | FR | FR |
| Time(min.) | 180 | 180 | 180 | 180 | 190 | 190 | 190 | 185 | 185 | 190 |
| Ppm | 2 | 2.4 | 2.6 | 2.6 | 2.1 | 2.5 | 2.8 | 3 | 3.8 | 3.9 |
| Volume | 8055.95 | 8108.60 | 8119.08 | 8129.24 | 8139.38 | 8149.04 | 8175.00 | 8194.64 | 8201.30 | 8229.75 |
| Ethylene | 2.76 | 3.43 | 3.74 | 3.77 | 2.90 | 3.48 | 3.96 | 4.42 | 5.62 | 5.73 |
| Mutant line($R_8P_{18}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 1762.5 | 1728.14 | 1719.23 | 1712.92 | 1705.71 | 1698.7 | 1670.52 | 1658.32 | 1650.25 | 1625.41 |
| Stage | UR | UR | QR | QR | QR | SR | SR | FR | FR | FR |
| Time(min.) | 180 | 180 | 200 | 200 | 175 | 175 | 180 | 180 | 190 | 190 |
| Ppm | 0.5 | 1.1 | 1.5 | 1.9 | 2.3 | 2.9 | 3 | 3.2 | 3.8 | 5.4 |
| Volume | 8237.50 | 8271.86 | 8280.77 | 8287.08 | 8294.29 | 8301.30 | 8329.48 | 8341.68 | 8349.75 | 8374.59 |
| Ethylene | 0.78 | 1.76 | 2.17 | 2.76 | 3.83 | 4.86 | 4.99 | 5.37 | 6.07 | 8.79 |
| Mutant line($R_7P_{18}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 1641.14 | 1590.07 | 1564.88 | 1572.76 | 1568.25 | 1551.68 | 1542.36 | 1531.78 | 1520 | 1500.67 |
| Stage | UR | UR | QR | QR | QR | SR | SR | FR | FR | FR |
| Time(min.) | 180 | 180 | 175 | 180 | 168 | 178 | 200 | 210 | 180 | 180 |
| Ppm | 1.1 | 1.5 | 1.8 | 2.4 | 2.7 | 3 | 3.5 | 3.7 | 4 | 4.9 |
| Volume | 8358.86 | 8409.93 | 8435.12 | 8427.24 | 8431.75 | 8448.32 | 8457.64 | 8468.22 | 8480.00 | 8499.33 |
| Ethylene | 1.87 | 2.64 | 3.33 | 4.29 | 5.18 | 5.51 | 5.76 | 5.84 | 7.44 | 9.25 |
| Mutant line($R_{18}P_{19}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 2094.6 | 2071.52 | 2044.51 | 2029.71 | 2016.38 | 2005.65 | 1991.47 | 1970.25 | 1950.65 | 1940.36 |
| Stage | UR | UR | QR | QR | QR | QR | SR | SR | FR | FR |
| Time(min.) | 200 | 200 | 180 | 180 | 175 | 175 | 170 | 172 | 180 | 180 |
| Ppm | 1.1 | 0.4 | 0.6 | 0.2 | 2.5 | 3.8 | 4.9 | 8.4 | 10.7 | 10.99 |
| Volume | 7905.40 | 7928.48 | 7955.49 | 7970.29 | 7983.62 | 7994.35 | 8008.53 | 8029.75 | 8049.35 | 8059.64 |
| Ethylene | 1.25 | 0.46 | 0.78 | 0.26 | 3.39 | 5.19 | 6.95 | 11.94 | 14.72 | 15.22 |

| Mutant line($R_4P_{16}$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
|---|---|---|---|---|---|---|---|---|---|---|
| Fruit weight(gm) | 2700.25 | 2695.63 | 2685.21 | 2674.32 | 2658.54 | 2645.26 | 2635.25 | 2600.25 | 2562.35 | 2522.21 |
| Stage | UR | UR | QR | QR | SR | SR | SR | FR | FR | FR |
| Time(min.) | 180 | 180 | 200 | 200 | 175 | 175 | 190 | 190 | 168 | 165 |
| Ppm | 1.1 | 1.2 | 1.5 | 1.9 | 2 | 2.5 | 3.5 | 4 | 5.4 | 6 |
| Volume | 7299.75 | 7304.37 | 7314.79 | 7325.68 | 7341.46 | 7354.74 | 7364.75 | 7399.75 | 7437.65 | 7477.79 |
| Ethylene | 0.99 | 1.08 | 1.23 | 1.56 | 1.89 | 2.38 | 3.09 | 3.59 | 5.60 | 6.47 |
| Mutant line($R_7P_4$) | 1day | 2day | 3day | 4day | 5day | 6day | 7day | 8day | 9day | 10day |
| Fruit weight(gm) | 1863.53 | 1856.36 | 1842.54 | 1832.89 | 1823.79 | 1816.99 | 1809.67 | 1796.23 | 1780.14 | 1765.78 |
| Stage | UR | UR | QR | QR | SR | SR | SR | FR | FR | FR |
| Time(min.) | 200 | 200 | 175 | 175 | 180 | 190 | 195 | 168 | 165 | 180 |
| Ppm | 1.5 | 1.7 | 1.9 | 1.9 | 2.2 | 2.5 | 3.7 | 4.5 | 5.9 | 6.7 |
| Volume | 8136.47 | 8143.64 | 8157.46 | 8167.11 | 8176.21 | 8183.01 | 8190.33 | 8203.77 | 8219.86 | 8234.22 |
| Ethylene | 1.96 | 2.24 | 2.88 | 2.90 | 3.29 | 3.56 | 5.15 | 7.34 | 9.91 | 10.41 |

**$R_{13}P_{10}$ Mutant line**

The data asserted that significant variations were noticed in the physiological loss in weight of papaya fruit during the period of storage for 10 days. The significant variations in fruit weight ranged from 2656.97 g to 2467.23 g. The respiration rate ranged from 24.33mg $CO_2$ kg/h to 56.01 mg $CO_2$ kg/h. However, 189.74 g decrease in fruit weight and an increase of 31.68 mg $CO_2$ kg/h was observed during 10 days and inverse relation between physiological loss of weight and respiration rate was observed. During respiration, there was a significant increase in volume of water consumed from 6466.22 ml to 6718.58 ml for 10 days(Graph1and 4). The ethylene production rate got increased from 0.92 µl/kg/h to 4.54 µl/kg/h and volume of water required for respiration ranged from 7343.03 ml to 7497.44 ml for 10 days. (Table 1 and 2).

**$R_6P_{18}$ Mutant line**

The data asserted that significant variations were noticed in the physiological loss in weight of papaya fruit during the period of storage for 10 days. The significant variations in fruit weight ranged from 1642.19 g to 1501.65 g. The respiration rate ranged from 50.75 mg $CO_2$ kg/h to 105.99 mg $CO_2$ kg/h. However, 140.54 g decrease in fruit weight and an increase of 55.24 mg $CO_2$ kg/h was observed during 10 days and inverse relation between physiological loss of weight and respiration rate was observed. During respiration there was a significant increase in volume of water consumed from 7815.88 ml to 8003.10 ml for 10 days(Graph1and 4). The ethylene production rate got increased from 1.87 µl/kg/h to 8.10 µl/kg/h and volume of water required for respiration ranged from 8357.81 ml to 8496.35 ml for 10 days. (Table 1 and 2).

**$R_3P_{14}$ Mutant line**

The data asserted that significant variations were noticed in the physiological loss in weight of papaya fruit during the period of storage for 10 days. The significant variations in fruit weight ranged from 1552.80 g to 1415.69 g. The respiration rate ranged from 27.25 mg $CO_2$ kg/h to 105.01 mg $CO_2$ kg/h. However, 137.11 g decrease in fruit weight and an increase of 77.76 mg $CO_2$ kg/h was observed during 10 days and inverse relation between physiological loss of weight and respiration rate was observed. During respiration, there was a significant increase in volume of water consumed from 7934.77 ml to 8117.10 ml for 10 days. The ethylene production rate got increased from 2.90 µl/kg/h to 8.29 µl/kg/h nd volume of water required for respiration ranged from 8447.20 ml to 8584.31 ml for 10 days. (Table 1 and 2) (Graph1and 4).

**$R_9P_{13}$ Mutant line**

The data revealed significant variations with respect to physiological loss in weight of papaya fruit during the period of storage for 10 days. The significant variations were found in fruit weight which ranged from 1944.05 g to 1770.25 g. The respiration rate ranged from 50.81 mg $CO_2$ kg/h to 84.55 mg $CO_2$ kg/h. However, 173.80 g decrease in fruit weight and an increase of 33.74 mg $CO_2$ kg/h was observed during 10 days and an inverse relation between physiological loss of weight and respiration rate was observed. During respiration there was significant increase in volume of water consumed from7414.41 ml to 7645.50 ml for 10 days. The ethylene production rate got increased from2.76 µl/kg/h to 5.73 µl/kg/h and volume of water required for respiration was ranged from 8055.95 ml to 8229.75 ml for 10 days (Table 1 and 2), ( Graph 2 and 5).

**$R_8P_{18}$ Mutant line**

The data indicated that significant variations in the physiological loss in weight of papaya fruit during the period of storage for 10 days. The significant variations were found in fruit weight which ranged from 1762.50 g to 1625.41 g. The respiration rate ranged from11.58 mg $CO_2$ kg/h to 103.22 mg $CO_2$ kg/h. However, 137.09 g decrease in fruit weight and an increase of 91.64 mg $CO_2$ kg/h was observed during 10 days and an inverse relation between physiological loss of weight and respiration rate was observed. During respiration, there was a significant increase in volume of water consumed from 7655.87 ml to 7838.20 ml for 10 days ( Graph 2 and 5). The ethylene production rate got increased from 0.78 µl/kg/h to 8.79 µl/kg/h and volume of water required for respiration was ranged from 8237.50 ml to 8374.59 ml for 10 days. (Table 1 and 2).

**$R_7P_{18}$ Mutant line**

The data indicated significant variations in the physiological loss in weight of papaya fruit during this period of storage for 10 days.

The significant variation was found in fruit weight which ranged from 1641.14 g to 1500.67 g. The respiration rate ranged from 31.75 mg $CO_2$ kg/h hr to 89.60 mg $CO_2$ kg/h. However, 140.47 g decrease in fruit weight and an increase of 57.85 mg $CO_2$ kg/h was observed during 10 days and an inverse relation between physiological loss of weight and respiration rate was observed. During respiration, there was a significant increase in volume of water consumed from 7817.28 ml to 8004.10 ml for 10 days (Fig.2 and Fig.5). The ethylene production rate got increased from 1.87 µl/kg/h to 9.25 µl/kg/h and volume of water required for respiration

was ranged from 8358.86 ml to 8499.33 ml for 10 days. (Table 1 and 2).

**$R_{18}P_{19}$ Mutant line**

The data revealed a significant variation in the physiological loss in weight of papaya fruit during the period of storage for 10 days. The significant variations were found in fruit weight which ranged from 2094.60 g to 1940.36 g. The respiration rate ranged from 9.18 mg $CO_2$ kg/h to 142.75 mg $CO_2$ kg/h. However, 154.24 g decrease in fruit weight and an increase of 133.57 mg $CO_2$ kg/h was observed during 10 days and an inverse relation between physiological loss of weight and respiration rate was observed. During respiration, there was a significant increase in volume of water consumed from 7241.18 ml to 7419.30 ml for 10 days. The ethylene production rate got increased from 1.25 µl/kg/h to 15.22 µl/kg/h( Fig 2 and Fig 5) and volume of water required for respiration ranged from 7905.40 ml to 8059.64 ml for 10 days. (Table 1 and 2).

**$R_6P_8$ Mutant line**

The data indicated significant variations in the physiological loss in weight of papaya fruit during the period of storage for 10 days. The significant variations were found in fruit weight which ranged from 1985.36 g to 1865.31 g. The respiration rate ranged from22.24 mg $CO_2$ kg/h to 99.29 mg $CO_2$ kg/h. However, 120.05 g decrease in fruit weight and an increase of 77.05 mg $CO_2$ kg/h was observed during 10 days and an inverse relation between physiological loss of weight and respiration rate was observed. During respiration, there was a significant increase in volume of water consumed from 7359.47 ml to 7519.10 ml for 10 days. The ethylene production rate got increased from 1.45 µl/kg/h to 7.56 µl/kg/h( Fig.3 and Fig.6) and volume of water required for respiration ranged from 8014.64 ml to 8134.69 ml for 10 days. (Table 1 and 2).

**$R_7P_4$ Mutant line**

The data revealed significant variations in the physiological loss in weight of papaya fruit during the period of storage for 10 days. The significant variations were found in fruit weight which ranged from 1863.53 g to 1765.78 g. The respiration rate ranged from24.21 mg $CO_2$ kg/h to 75.39 mg $CO_2$ kg/h. However, 97.75 g decrease in fruit weight and an increase of 51.18 mg $CO_2$ kg/h was observed during 10 days and an inverse relation between physiological loss of weight and respiration rate was observed. During respiration, there was a significant increase in volume of water consumed from 7521.50 ml to 7651.50 ml for 10 days (Fig.3 and Fig.6). The ethylene production rate got increased from 1.96 µl/kg/h to 10.41 µl/kg/h and volume of water required for respiration got ranged from 8136.47 ml to 8234.22 ml for 10 days. (Table 1 and 2)

**$R_4P_{16}$ Mutant line**

The data indicated significant variations in the physiological loss in weight of papaya fruit during the period of storage for 10 days. The significant variations were found in fruit weight which ranged from 2700.25 g to 2522.21 g. The respiration rate ranged from 11.39 mg $CO_2$ kg/h to 71.13 mg $CO_2$ kg/h. However, 178.04 g decrease in fruit weight and an increase of 59.74 mg $CO_2$ kg/h was observed during 10 days and an inverse relation between physiological loss of weight and respiration rate was observed (Fig 3 and Fig 5). During respiration, there was a significant increase in volume of water consumed from 6408.66 ml to 6645.40 ml for 10 days( Fig.3 and Fig.6). The ethylene production rate was increased from 0.99 µl/kg/h to 6.47 µl/kg/h and volume of water required for respiration ranged from 7299.75 ml to 7477.79 ml for 10 days ( Table 1 and Table 2).

The optimum dose of gamma (500 Gy) and EMS (0.50 %) resulted in more number of days to ripen from maturity. The lower concentration did not affect variation in shelf life. It may be due to the reason that too low concentration resulted in no variation and too higher concentration resulted in lethality of seedlings before emergence. This result was in close proximity with the findings of (DO *et al*., 2005) who reported that increased concentration resulted in abnormalities with respect morphological traits, sterility and fruit shape.

Mutation can be an effective breeding method for improvement of shelf life as this is a major problem in highly perishable fruit crops. Successful mutants with increased shelf life were produced in apple var. Golden Delicious (De Figueredo *et al*., 2014) tomato, melon (Mccallum *et al*., 2008) upon gamma irradiation. treated with 250 Gy of γ-irradiation frequently softened more uniformly than non-irradiated fruit.

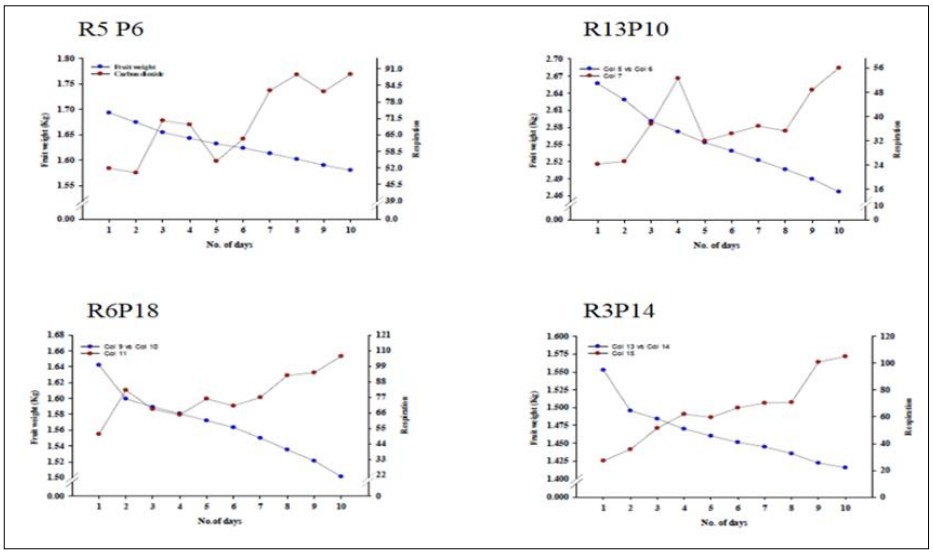


**Fig 4:** Graph depicting fruit weight, number of days and respiration in $M_2$ mutant lines

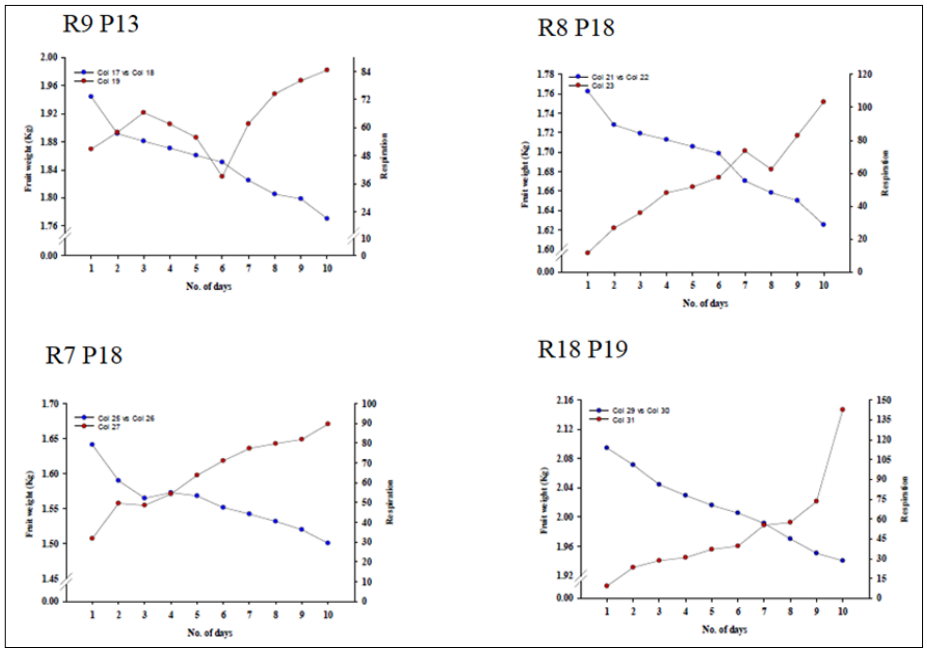


**Fig 5:** Graph depicting fruit weight, number of days and respiration in $M_2$mutant lines

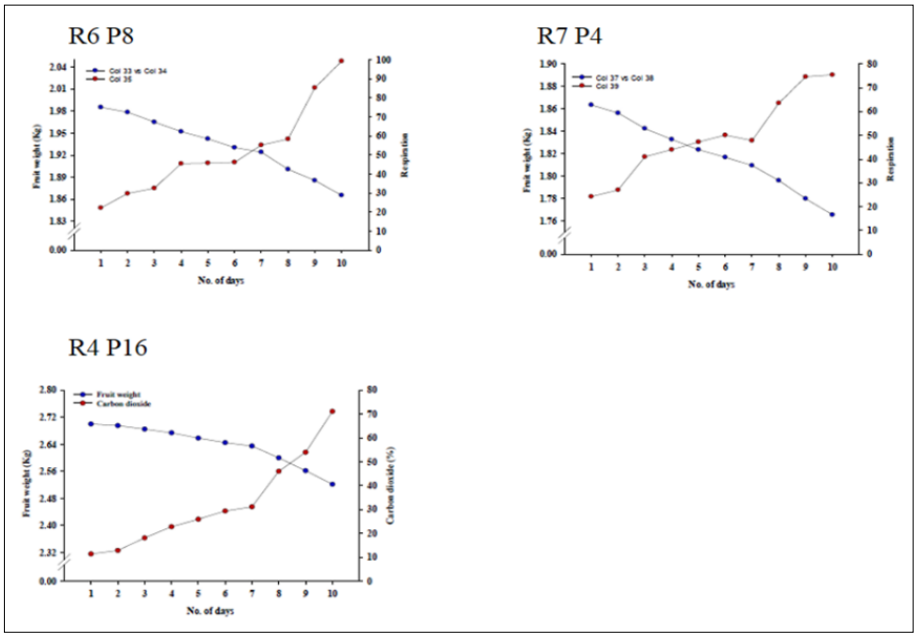


**Fig 6:** Graph depicting fruit weight, number of days and respiration in $M_2$ mutant lines

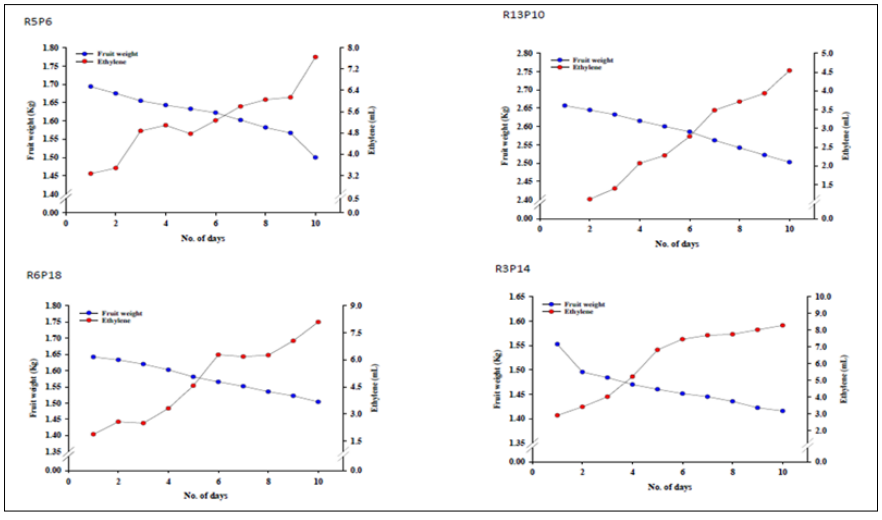


**Fig 7:** Graph depicting fruit weight, number of days and ethylene content in $M_2$ mutant lines

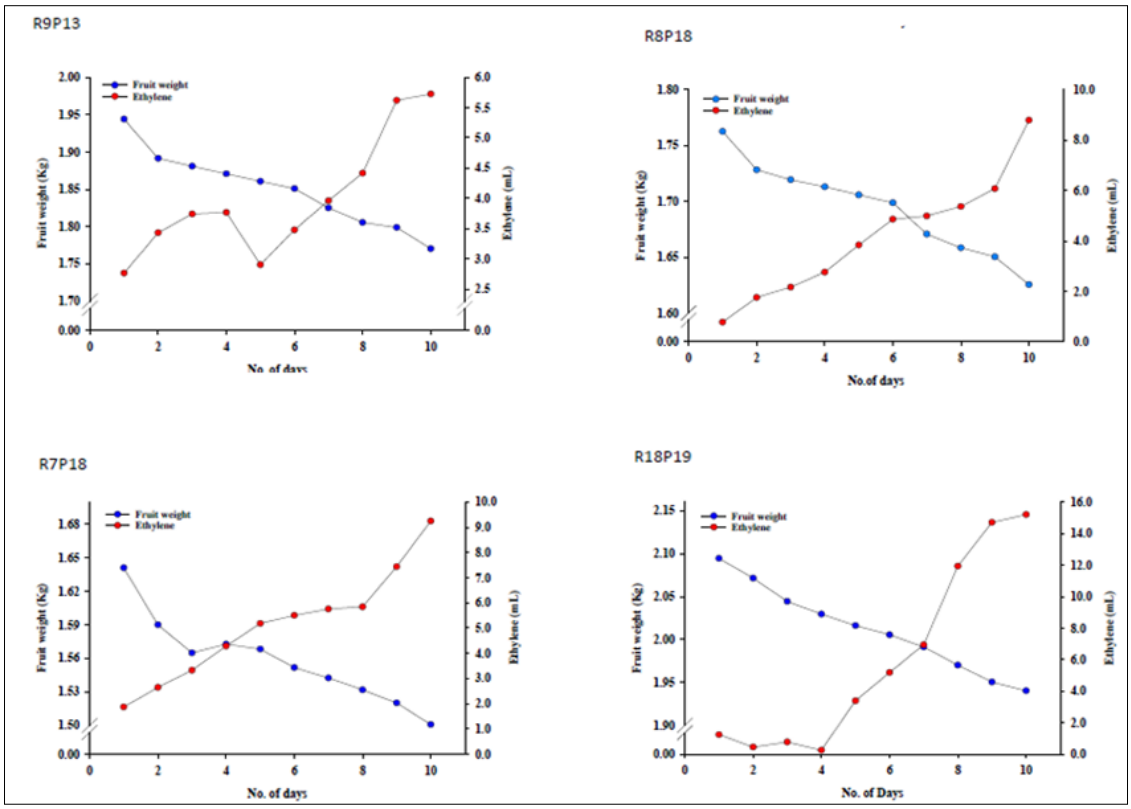


**Fig 8:** Graph depicting fruit weight, number of days and ethylene content in $M_2$ mutant lines

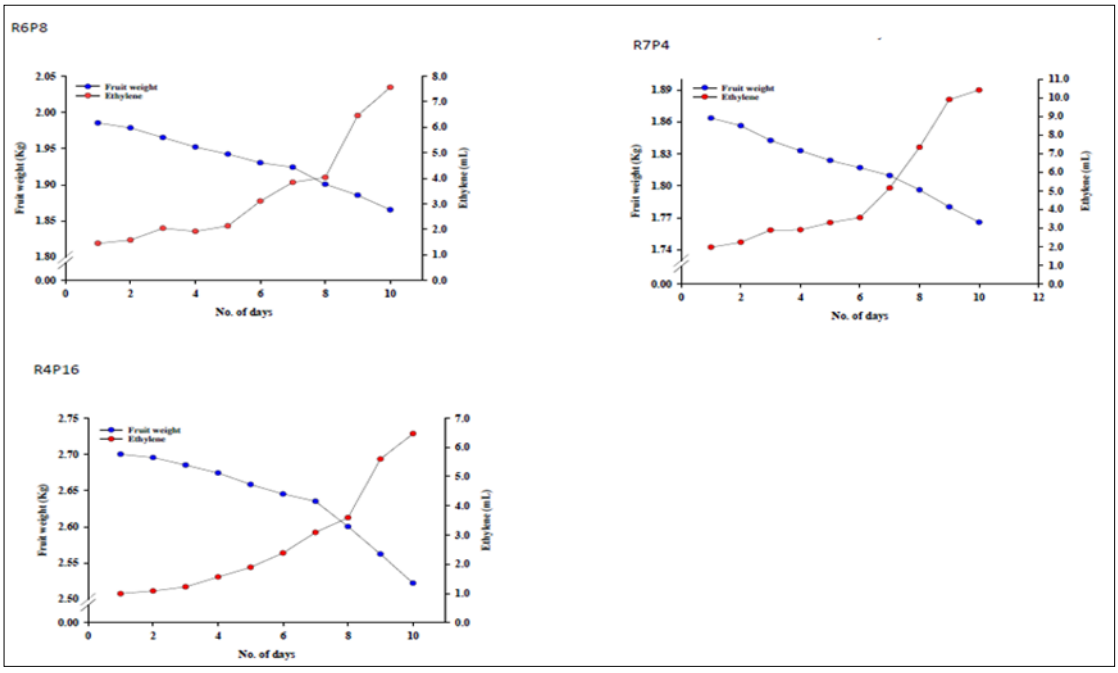


**Fig 9:** Graph depicting fruit weight, number of days and ethylene content in $M_2$ mutant lines

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