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1. গবেষণা প্রকল্পের শিরোনামঃ

Study on use of artificial fruit ripening agents and development of fruit ripening chamber.

2. প্রধান গবেষকের নাম, পদবি, ঠিকানা এবং সন:

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3. বন্ধু-সংক্ষেপঃ (এক হাজার শব্দের মধ্যে অবশ্যই Soft copy জমা দিতে হবে)

Determining the ideal ethylene gas concentration for tomato and banana ripening, as well as their impact on fruit quality, are the goals of this research. We set up the current experiment in an indoor house at Sher-e-Bangla Agricultural University's horticultural farm in Dhaka, using a completely randomized design with four treatments and three replications. The sources of ethylene used were ethylene gases. We observed three concentrations of 50, 100, and 150 ppm for each ethylene gas and ethephon. Ripening chamber fruits treated with ethylene gas were maintained at 20⁰C and 85–90% relative humidity for a maximum of 36 hours. There were noticeable alterations in the fruit's color, with the green hue turning yellow. Comparably, the concentration and time after treatment increased the trend of the chemical parameters, namely TSS, decreasing sugar, and total sugar. With the ripening process and the increase in ethylene gas concentration, there was a progressive drop in titratable acidity. We found lower acidity in fruits treated with ethylene gas. Up to eight days of ambient storage, it was discovered that the physiological loss in weight (PLW) increased with the length of the storage period regardless of interventions. Among the various treatments, banana fruits treated with 150 ppm ethylene gas had the highest PLW. We found that an increase in ethylene gas concentration accelerated the ripening process of bananas. On the fourth day of ripening, banana fruits treated with ethylene gas had a sensory score that was considerably higher, indicating that they were well-accepted. Researchers found that ripening bananas at 20°C for 36 hours with 150 ppm of ethylene gas in an inexpensive ripening chamber with an RH of 85–90% is the safest method. Another study investigates the impact of ethylene gas on the quality and ripening of winter tomatoes. We placed the fully grown green tomatoes in the ripening chamber and allowed them to ripen for 24 hours at 20 ± 1°C and 90-95% relative humidity. Next, we treated them with varying amounts of ethylene gas (50, 75, and 100 ppm). Fruits from the fully green to the senescent stages of development had their physico-chemical characteristics examined. The ripening percentage was highest in the treatment with ethylene gas (100 ppm). The proportion of fruits that ripened and rotted rose as the ethylene concentration (50–75 ppm) and the number

of days the fruits were left to ripen increased. When the ripening period progressed, the titratable acidity of the fruits decreased linearly, but their ascorbic acid and lycopene content increased regardless of treatment. Ethylene gas treatment (100 ppm) produced uniformly red fruits with a suitable firmness, minimal rotting, and acceptable quality after 9 days of ripening; for these reasons, it is preferable to alternative treatments. Although the fruits took longer (11 days) to ripen evenly, the control group's fruits showed comparable ripening, firmness, rotting, and quality results to those of the ethylene gas (100 ppm) treatment. The present project also aims to compare and analyze the effectiveness of the use of ripening agents supporting existing policies and regulations regarding artificial fruit ripening to find out the best possible solution.

4. সূচনা ও পটভূমিঃ

Fruits and vegetables are the natural source of vitamins, minerals, and nutrients that play an important role in the human diet. Banana (*Musa sp.*) and tomato (*Solanum lycopersicum*) are two major fruit crops in Bangladesh. These fruits are harvested at maturity to reduce postharvest loss and need to be ripened before reaching to consumer. According to the commodities, postharvest losses in fresh fruits and vegetables range from 5 to 25% in developed countries to 20 to 50% in developing countries (Verma and Joshi 2000). Different fruit ripening agents can be used to ripen fruits quickly and artificially, giving them the correct color and flavor. The need for more research on the subject is reinforced by recent findings on the potential health risks linked to artificial fruit ripening and artificial fruit ripening chemicals (Rahman et al., 2008, Siddiqui and Dhua, 2010). A hormone called ethylene that is naturally generated in fruit governs fruit ripening by starting or stopping a few chemical and biological processes (Theologis, 1992). Although the fruit itself produces ethylene, ripening may also be accelerated by ethylene treatment. The use of ethylene does not significantly affect the physiological changes that take place during ripening. For instance, the amount of starch and sugar, acidity and pectic component concentration in ethylene-treated and untreated control fruit are roughly equal at the same stage of ripening (Agravante et al., 1990). The main way that post-harvest ethylene treatment affects physiology is by accelerating the ripening process's related alterations. Exogenous ethylene application boosts ethylene production and shortens the pre-climacteric phase by around seven days in fruit of a Cavendish banana type (Agravante et al., 1991). Time to ripen of all the climacteric fruits increased linearly with logarithmic reduction in ethylene concentration across the whole concentration range studied. Mature, unripe mango and tomato were held at 20 C in air containing ethylene at 0.005, 0.01, 0.1 1.0 and 10 L/L (Wills, 2001). The duration of ethylene conditioning needed to fully induce ripening was longer at lower temperatures: 72 h at 5 degrees C, 48 h at 10 degrees C, and 24 h at 20 degrees C. and cold storage in air for as little as 3-4 days at 5 or 10 degrees C appeared to hasten subsequent ripening (Agar et al., 2000). Bananas that have been exposed to exogenous ethylene mature more quickly and have higher levels of endogenous ethylene (Burg and Burg, 1965) and banana ripening can be accelerated with ethylene concentrations as low as 0.1 ppm (Burg and Burg, 1967). When exposed to exogenous ethylene at a concentration of 100 ppm for 12 hours, endogenous ethylene and CO₂ production are quickly increased, mimicking a respiratory climacteric. Additionally, this study demonstrated that an increase in respiration relies on the length of the therapy, with a 12-hour treatment being marginally more beneficial than a 6-hour treatment (Dominguez and Vendrell, 1994).

Under this project, a mobile fruit ripening chamber has already been established and ethylene cylinder has been attached to this chamber and experiment has been conducted. The present project also aims to compare and analyses the effectiveness of the use of ripening agents supporting existing policies and regulations regarding artificial fruit ripening to find out the best possible solution.

5. গবেষণা কার্য শুরু ও সমাপ্তির নির্ধারিত তারিখঃ Aug 2023 to March 2024.
6. গবেষণার অনুসৃত পদ্ধতি/পরীক্ষাসমূহঃ

6.1 Experimental Site: This experiment was conducted in an indoor house in the field of Horticultural Farm, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during Aug 2023 to March 2024.

6.2 Experimental materials: The controlled ripening of bananas with ethylene was achieved using a low-cost ripening chamber. The specification of ripening chamber given below:

No	Description	Size
A	Chamber Structure	
01.	PU sandwich panel Board (For Wall) Color-Off-white.	75 mm
02.	Aluminium U Channel (Powder coated)	40*75*40 mm
03.	Aluminium L Capping (Powder coated)	150*100 mm
04	Aluminium L Capping (Powder coated)	75*50 mm
05.	PPGI Angle	100*75 mm
06.	Silicon	300 ml
07.	SS Star Screw	50 mm
08.	Royal Plug	12 no
09.	Roofing Screw	100 mm
10.	Rivet	3.2 mm
11.	MS Hollow Box (For Structure)	75*50 mm
12.	Welding rod, cutting disk, Paint	
13.	Wheel 250 & lock system	250 mm
14.	Pu Sandwich Panel Door	2100*1000 mm
B	Cooling System	
1	Air Cooler capacity	18000 BTU
2	Cooling gas	R 32
C	Controller System	

1	Ethylene Sensor	Electromagnetics Sensor
2	Temp and Humidity Sensor	DHT22
3	Ethylene Gas Cylinder –	3000-4000 PSI

The ethylene gas was introduced into the chamber using a portable ethylene gas cylinder with a capacity of 17 kg. The gas was released for a specific duration, with 4 seconds for a concentration of 50 ppm, 8 seconds for a concentration of 100 ppm, and 12 seconds for a concentration of 150 ppm. The duration of each treatment was measured using a gas analyzer. After being exposed

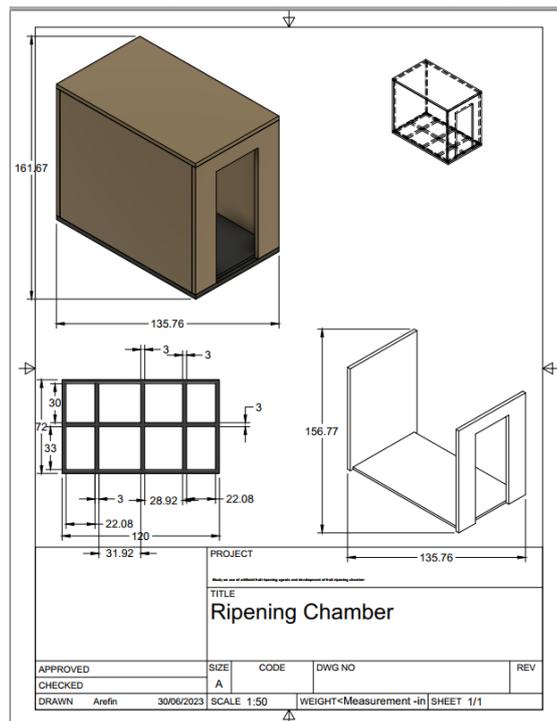


Fig.: 1- Design of the ripening chamber under this study

to ethylene for 36 hours, the fruit in the crates were kept at a temperature of 20°C for a further 12 hours and then exposed to room temperatures.

6.2.1 Effect of ethylene gas on the ripening of Banana

6.2.1.1 Experimental Design: Seven treatments and three replications were used in the completely randomized design of the experiment. For this investigation, firm green banana fruits of the Grand Naine variety that were physiologically mature were collected. To drain the latex from the sliced section, the hands were carefully removed from the bunch and delatexed. Each bunch's top and bottom banana hands were removed since they weren't appropriate for tests on banana ripening. After properly cleaning their hands with potable water to get rid of any dirt or foreign objects, a selection of banana hands was treated with the fungicide carbendazim (0.2%) for five minutes and allowed to dry in the shade. Different amounts of ethylene gas (T1–50 ppm, T2–100 ppm, and T3–150 ppm) and ethephon (T4–50 ppm, T5–100 ppm, and T6–150 ppm) were applied to the banana hands, with T7 serving as the absolute control (untreated fruits). Low-cost ripening chambers were employed in the procedures.

A portable 1.6-liter ethylene gas cylinder was used to release the ethylene gas into the chamber for the designated amount of time (4 seconds for 50 ppm, 8 seconds for 100 ppm, and 12 seconds for 150 ppm), as determined by the treatment and monitored using a gas analyzer. Following a 36-hour ethylene

exposure, the fruit-containing crates were kept at 20°C for an additional 12 hours before being brought to room temperature. Well-prepared fruits were placed in crates and left to mature in natural light after being dipped in ethephon solutions at concentrations of 50 ppm, 100 ppm, and 150 ppm for five minutes.

The observations on different physicochemical and physiological parameters were recorded at an interval of two days 2nd, 4th, 6th and 8th day of treatment.

6.3 Physical parameters

6.3.1 Fruits firmness (kg/cm²): The measurement of fruit firmness was conducted using a pocket penetrometer (Fruit Tester FT 327), and the quantification of firmness was reported as kg/cm² (Desai and Deshpande, 1975). The hardness of the fruit was measured at two-day intervals, and punctures were done at two specific points on the fruit surface using a probe. The average firmness was then calculated.

6.3.2 Colour: As suggested by Venkata Subbaiah *et al.*, 2013, external colour was divided into eight stages 1. Green 2. Green trace of yellow 3. More green than yellow 4. More yellow than green 5. Yellow trace of green 6. Yellow 7. Yellow with brown spots 8. Yellow with increasing black areas.

6.4 Bio-chemical parameters

6.4.1 Total Soluble Solids (°Brix): The level of Total Soluble Solids was determined using a pocket refractometer (Atago, Japan) with a range of 0-320Brix. This was achieved by diluting the pulp with deionized water.

6.4.2 Total sugars (%): Total sugars were determined as per the method of suggested by Ranganna (1986) and were worked out by using following formulae-

$$\text{Total sugars (\%)} = \frac{\text{Factor} \times \text{volume made} \times 100}{*\text{B.R.} \times \text{wt. of sample}}$$

* B.R. means burette reading.

6.4.3 Physiological loss in weight (%): The changes in physiological loss in weight (PLW) in both treated and controlled fruits were recorded during storage every alternate day and were expressed in percentage. To work out the following formula was used.

$$\text{PLW (\%)} = \frac{\text{Initial Wt. (g)} - \text{Final Wt. (g)}}{\text{Initial Wt. (g)}} \times 100$$

6.4.4 Organoleptic taste: The organoleptic evaluation for assessing the flavour, taste (sweetness), texture (palatability) and overall acceptability of ripe banana fruits was carried out by the panels of twenty-five judges by using 9 points Hedonic scale (Amerine, 1965).

6.5 Statistical analysis

As the experiment was designed Completely Randomized Design, the analysis of the data generated on changes physicochemical and physiological parameters of banana was carried out as per the method described by Panse and Sukhatme (1995).

7. Effect of ethylene gas on the ripening of Tomato in the ripening chamber

7.1 Experimental design: The tomato fruits were collected during the initial week of February from the field of a progressive farmer in the Manikganj district. Before harvesting, the fruits were subjected

to pre-cooling utilizing a forced air-cooling system. Following the pre-cooling process, the fruits that were bruised and infected were separated, and only the healthy fruits of uniform size were chosen for the current investigation. Prior to administering the ripening treatments, ten tomato fruits were selected at random from the batch of experimental fruits and their physico-chemical characteristics were evaluated.

Each hybrid's tomato fruits were divided into four lots. The first, second, and third lots were subjected to ethylene gas concentrations of 50 ppm, 75 ppm, and 100 ppm, respectively, within the ripening chamber for a duration of 24 hours ($30 \pm 1^\circ\text{C}$ and 90-95% RH). This exposure was facilitated by employing a portable ethylene gas cylinder. The fourth batch was inoculated and retained as the control. The fruit's surface was desiccated and placed in plastic containers, which were then stored in a walk-in ripening room at a temperature of $20 \pm 1^\circ\text{C}$ and a relative humidity of 90-95%. The data pertaining to different physico-chemical properties were documented starting from the third day following treatment, with measurements taken at one-day intervals throughout a duration of 13 days.

7.2 Fruit quality analysis

Total soluble solids (TSS) concentration of fruit flesh was determined by an Erna Hand refractometer (Tokyo, Japan) and results are reported as °Brix at 20°C .

To conduct ascorbic acid analysis, a fresh fruit sample weighing 10 g was subjected to homogenization using a 25 ml solution of metaphosphoric acid acetic acid (MPA). Subsequently, the mixture was filtered to achieve a final volume of 100 ml using MPA. A 10 ml volume of the filtrate was extracted and subjected to titration using a standard indophenol solution. The conclusion was denoted by the manifestation of a pale pink hue, which endured for around 15 seconds. The measurement of the standard indophenol solution was recorded for a sample weighing 10 g, and it was conveyed as milligrams of ascorbic acid per 100 grams of fresh weight. The determination of ascorbic acid was performed using the formula $V \times S \times D$, where V represents the volume of the standard indophenol solution employed for this sample, S denotes the standardization value (measured in mg ascorbic acid per milliliter of indophenol solution), and D signifies the dilution factor. The dilution factor was determined using the formula $A / (B \times C) \times 100$, where A represents the volume of the sample, B represents the volume of the aliquot taken, and C represents the weight of the sample taken.

To analyze the lycopene concentration, a fresh fruit sample weighing 20 g was extracted using 40-50 ml of acetone in 4-5 separate batches. Subsequently, strain it and remove acetone until it is completely dry. To the residue, incorporate petroleum ether and adjust the volume to 25 ml. Proceed to measure the optical density (OD) at a wavelength of 505 nm using an absorption low colorimeter, as specified by the AOAC (2010). The lycopene concentration was determined using the formula: $A / B \times \text{OD}$ at 505 nm, where A represents the final volume (25 ml) and B represents the dosage of the sample (20 g). The findings were quantified in milligrams per 100 grams of fresh weight.

7.3 Measurement of physiological loss in weight and ripening

The calculation of physiological weight loss was performed using the fresh weight foundation, employing the formula $(A - B) / A \times 100$. In this formula, A represents the weight of the fruit immediately prior to storage, while B represents the weight of the fruit after a specific storage duration. The color determination of each sample involved measuring the reflectance spectra at two distinct locations on the fruit surface, followed by obtaining the mean reflectance spectrum.

The ripening percentage of the fruits was estimated by counting the total number of ripened fruits on the basis of their appearance and desirable colour with the help of tomato colour chart and results were expressed in %. Ripening percentage is calculated by the following formula: $A/B \times 100$, where A is the number of fully ripened fruits and B is the total number of fruits.

Photos of ripening chamber and experiments



Ripening Chamber



Banana collection



Cutting & sorting of Banana



Washing & Grading of Banana



Pre-treatment data Collection



Ethylene Treatment in Ripening Chamber



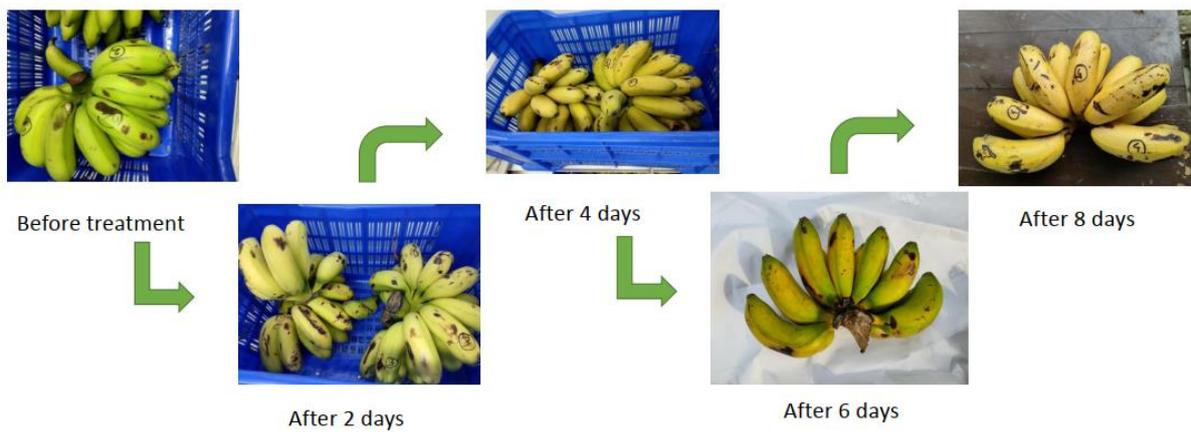
Post-treatment data collection



Color variation among different treatment after 8 days



Color variation due to ethylene treatment



Flow chart of color change during ethylene treatment

1. ফলাফল ও আলোচনাঃ (সারণী, লেখ-চিত্র, চার্ট ইত্যাদির আকারে যখন যাহা প্রয়োজনীয়, এইরূপ উপাত্ত সন্নিবেশিত করিতে হইবে)

7. Results and Discussion:

7.1 Effect of ethylene gas on physical parameters of banana during ripening

7.1.1 Peel colour

The banana fingers were greenish when they were harvested, but as they ripened, the green hue changed to a variety of shades: uniform yellow, yellow with brown specks, more green than yellow, and dark black when the bananas were stored (Table 1).

On the fourth day following treatment, it was clear that the fruits treated with 150 ppm ethylene gas (T3) and 100 ppm ethylene gas (T2) had become yellow. On the second, fourth, sixth, and eighth day of observation, the treatment T3 (150 ppm ethylene gas) showed the most notable change in peel colour, with scores of 5.00, 6.00, 7.67, and 8. The fruits treated with ethephon showed nearly the same trend in T5 (100 ppm ethephon) and T6 (150 ppm ethephon) treatments. However, Treatment T3 (150 ppm ethylene gas) registered the highest score.

A consumer's consideration of banana fruit hue is significant. The most noticeable change that takes place during ripening is the peel's colour changing from green to yellow, which can be used as an approximate indicator of when the fruit is ready (Palmer, 1971). Significant colour changes were seen in all ethylene gas and ethephon treatments, and the colour changes happened more quickly as the concentration rose. Furthermore, banana fruits exposed to ethylene gas showed faster colour improvement than those treated with ethephon. Additionally, this procedure produced homogeneous colour development.

Table 1. Effect of ethylene gas on peel colour during ripening of banana

Treatment Number	Treatments	Days after treatment			
		2	4	6	8
T ₁	50 ppm ethylene gas	3.00	5.00	7.00	8.00
T ₂	100 ppm ethylene gas	4.00	5.67	7.00	7.67
T ₃	150 ppm ethylene gas	5.00	6.00	7.67	8.00
T ₄	50 ppm ethephon	1.00	3.00	5.00	7.00
T ₅	100 ppm ethephon	2.00	5.00	7.00	8.00
T ₆	150 ppm ethephon	3.00	5.67	7.00	8.00
T ₇	Control	1.00	2.00	3.00	4.00

S.E.±	0.21	0.21	0.21	0.12
C.D. at 5 %	0.66	0.66	0.66	0.33

In the current study, treatment T3 (150 ppm ethylene gas) showed much faster colour improvement, with scores of 5.00, 6.00, 7.67, and 7.67 on the second, fourth, sixth, and eighth treatment days. On the fourth day of treatment, the treatment T3 (150 ppm ethylene gas) showed the most consistent and acceptable yellow tint. Black dots started to show up on the peel on days six and eight after treatment, and as time went on, the peel quickly lost its marketable quality. Fruits were marketable until the fourth day following treatment.

In bananas, ethylene gas and ethylene-releasing chemicals have been shown to cause colour development. This has been extensively reported by researchers such as Rao et al. (1971), Patil (2003), Mahajan et al. (2010), Tapre and Jain (2012), and Mebratie et al. (2015). According to Reyes and Paul (1995), the ripening process may cause a change in colour as a result of the synthesis of carotenoids and the concurrent loss of chlorophyll.

7.1.2 Fruit firmness (kg/cm²)

As ripening progressed, there was a noticeable decrease in the hardness of the banana fruits across all treatments (Table 2). On the second, fourth, sixth, and eighth days of treatment, respectively, the fruit firmness measured under treatment T3, or 150 ppm ethylene gas, was 3.50, 2.60, 1.90, and 1.20 kg/cm². This represents a considerable loss in fruit firmness. On the fourth, sixth, and eighth days of treatment, treatment T3 (150 ppm ethylene gas) and treatment T2 (100 ppm ethylene gas) were comparable to one another. On the second, fourth, sixth, and eighth days of treatment, respectively, the maximum fruit firmness was measured in untreated fruits, or T7, and it was recorded at 12.53, 10.70, 8.17, and 5.97 (kg/cm²). The results shows that there was a linear decline in fruit firmness in all treatments and that the firmness loss occurred more quickly when fruits were exposed to both ethylene sources. Furthermore, banana fruits exposed to ethylene gas lost more firmness than ones treated with ethephon.

Table 2. Effect of ethylene gas on fruit firmness during ripening of banana

Treatment Number	Treatments	Days after treatment			
		2	4	6	8
T ₁	50 ppm ethylene gas	5.40	4.90	3.53	2.20
T ₂	100 ppm ethylene gas	4.57	2.67	2.23	1.77
T ₃	150 ppm ethylene gas	3.50	2.60	1.90	1.20
T ₄	50 ppm ethephon	10.70	8.70	7.33	5.97
T ₅	100 ppm ethephon	9.00	8.27	7.00	5.80
T ₆	150 ppm ethephon	8.17	6.47	5.40	3.73
T ₇	Control	12.53	10.70	8.17	5.93

S.E.±	0.28	0.21	0.16	0.18
C.D. at 5 %	0.85	0.66	0.50	0.57

The findings of Sane et al. (2005), Imsabai et al. (2006), Mahajan et al. (2010), Kulkarni et al. (2011), Mebratie et al. (2015), and Patil and Shanmugasundaram (2015) align with the results obtained in this study. Montalvo et al. (2007), Laguneset al. (2007), and William et al. (2009) also documented comparable findings in the context of mango.

According to Brinstone et al. (1988), the decline in firmness observed during the ripening process can be attributed to the conversion of insoluble protopectin into soluble pectin or the disintegration of cells, resulting in increased membrane permeability. The depletion of pectin compounds within the middle lamella of the cell wall is a crucial factor in the ripening process, resulting in the deterioration of cell wall integrity and subsequent reduction in firmness and softness (Watada, 1986; Mahajan et al., 2010; Chauhan et al., 2012). Patil and Shanmugasundaram (2015) suggest that the softening of fruits can be attributed to the breakdown of nutrients and the subsequent increase in moisture content of the pulp. On the fourth day of treatment, the fruits obtained from treatment T3 exhibited favorable customer acceptability.

7.2 Effect of ethylene gas on Physio-chemical parameters of banana during ripening

7.2.1 Total Soluble Solids (°Brix)

Table 3 makes it clear that there was a rise in TSS of bananas up until the fourth day of treatment, and that there was a decrease in TSS in the source of ethylene gas treatments starting on the sixth day of treatment. On the other hand, TSS in the source of ethephon treatments decreased on the eighth day of therapy, whereas TSS in bananas increased up until the sixth day of treatment. It was also noted that on the second and fourth treatment days, the banana treated with 150 ppm ethylene, or treatment T3, recorded the highest TSS values (17.9 B and 22.8 0Brix), which was followed by the banana fruit treated with 100 ppm ethylene gas (17.6 B and 21.7 B, respectively). On the sixth day of the treatment, the treatment with the highest TSS was T5, or banana fruits treated with 100 ppm ethephon, which recorded 22.1 °B TSS. T6, or banana fruits treated with 150 ppm ethephon, recorded 21.60Brix. However, it was notable that the treatment 50 ppm ethephon recorded a significantly highest TSS of 20.60Brix on the eighth day of therapy.

In the current investigation, the treatment T3, which involved treating bananas with 150 ppm ethylene, had the highest TSS on the second and fourth treatment days (17.90 and 22.8 0 BB, respectively), followed by the treatment T2, which involved treating banana fruit with 100 ppm ethylene gas (17.6 00 BB and 21.7 0 BB, respectively). Up until the fourth day of treatment, the TSS was higher in the fruits treated with ethylene gas. Fruit had no commercial quality even though Treatment T4 (Ethephon 50 ppm) had the greatest TSS on the eighth day of the treatment, followed by Treatment T5 (Ethephon 100 ppm). Increased TSS has been linked to faster banana ripening, according to studies by Patil (2003), Saiprasad et al. (2008), Kulkarni et al. (2011), and Hailu et al. (2013).

Table 3. Effect of ethylene gas on TSS (°Brix) during ripening of banana

Treatment Number	Treatments	Days after treatment			
		2	4	6	8
T ₁	50 ppm ethylene gas	15.9	20.5	18.3	16.0
T ₂	100 ppm ethylene gas	17.6	21.7	19.2	18.9
T ₃	150 ppm ethylene gas	17.9	22.8	20.1	18.1
T ₄	50 ppm ethephon	7.1	19.7	21.0	20.6
T ₅	100 ppm ethephon	10.9	20.2	22.0	19.7
T ₆	150 ppm ethephon	16.7	20.8	21.6	19.3
T ₇	Control	4.07	4.53	16.1	16.5
	S.E.±	0.16	0.15	0.09	0.13
	C.D. at 5 %	0.50	0.47	0.27	0.41

Patil (2003), Saiprasad et al. (2008), Kulkarni et al. (2011), and Hailu et al. (2013) have shown an increase in total soluble solids (TSS) as the ripening of bananas progresses. The elevation in total soluble solids (TSS) levels can be ascribed to the hydrolysis of starch into monosaccharides during the ripening phase (Dadzie and Orchard, 1997), as well as the augmentation of organic solute concentration due to water depletion (Ryall and Pentzer, 1982). The observed reduction in total soluble solids (TSS) during the later stages of ripening, specifically on the 6th and 8th day, can perhaps be attributed to the conversion of some sugars into volatile organic acids, which are then utilized for respiration.

7.2.2 Total sugars (%)

The total sugars increased in all ethylene gas and ethephon treatments, and the growth was linear. T₃ (150 ppm ethylene gas) showed total sugars of 10.84%, 16.93%, and 21.49% on the second, fourth, and sixth day after treatment, which was noticeably higher than the other treatments. On the eighth day of treatment, treatment T₂, or 100 ppm ethylene gas (22.05%), was comparable to treatment T₃, or 150 ppm ethylene gas (22.21%). The treatment T₇ (Control) showed the lowest total sugar levels, which were 2.63 %, 3.13 %, 6.44 %, and 8.22% on the second, fourth, sixth, and eighth days of treatment while being stored at room temperature.

On the eighth day of treatment, when total sugar levels were reported at 22.05%, treatment T₂, or 100 ppm ethylene gas, performed on par with treatment T₃. The fruits treated with varying concentrations of ethephon showed the highest total sugar content in treatment T₆, or 150 ppm ethephon, on the second, fourth, sixth, and eighth days of treatment, with respective values of 5.40%, 10.52%, 14.51%, and 16.74%.

Table 4. Effect of ethylene gas on total sugar during ripening of banana

Treatment Number	Treatments	Days after treatment			
		2	4	6	8
T ₁	50 ppm ethylene gas	9.2	15.2	19.4	21.1
T ₂	100 ppm ethylene gas	10.1	16.4	21.1	22.0
T ₃	150 ppm ethylene gas	10.8	16.9	21.4	22.2
T ₄	50 ppm ethephon	2.6	3.3	7.4	13.5
T ₅	100 ppm ethephon	3.1	8.3	9.9	14.5
T ₆	150 ppm ethephon	5.4	10.5	14.5	16.7
T ₇	Control	2.6	3.1	6.44	8.22
	S.E.±	0.05	0.10	0.06	0.14
	C.D. at 5 %	0.17	0.31	0.19	0.43

Increase in total sugars during ripening could be ascribed to hydrolysis of starch into soluble sugars in the presence of ripening enzymes (Sarode and Tayade, 2009; Venkatasubbaiah et al., 2013).

7.2.3 Physiological Loss in Weight (PLW) (%)

The findings demonstrated that every source of ethylene had a significant impact on this parameter (Table 3). Along with the fruit's maturing process, there was also a noticeable and quick drop in weight. The PLW was 7.67%, 14.65%, 22.08%, and 31.05% on the second, fourth, sixth, and eighth day after treatment, with the highest percentage occurring in treatment T₃ (150 ppm ethylene gas). On the second, fourth, sixth, and eighth day of treatment, the treatment T₂ (100 ppm ethylene gas) recorded 6.22%, 14.05%, 20.90%, and 28.22%. The treatment T₃ (150 ppm ethylene gas) was followed by the treatment T₂. There was no difference between the T₃ and T₂ treatments. T₇ (Control), or untreated fruits, showed the lowest physiological loss in weight (%) of 2.43%, 5.22%, 9.10%, and 13.25% on the second, fourth, sixth, and eighth day, respectively. Additionally, the data made it clear that the PLW rose as the ethylene gas concentration rose. Additionally, it was shown that fruits treated with ethylene gas had higher percentages of PLW than fruits treated with ethephon.

Table 5. Effect of ethylene gas on PLW (%) during ripening of banana

Treatment Number	Treatments	Days after treatment			
		2	4	6	8
T ₁	50 ppm ethylene gas	5.85	9.81	14.71	19.42
T ₂	100 ppm ethylene gas	6.22	14.05	20.90	28.22
T ₃	150 ppm ethylene gas	7.67	14.65	22.08	31.05
T ₄	50 ppm ethephon	2.84	6.41	10.13	14.35
T ₅	100 ppm ethephon	2.75	6.44	10.62	14.79
T ₆	150 ppm ethephon	3.93	8.38	13.13	18.54
T ₇	Control	2.43	5.22	9.10	13.25
	S.E.±	0.515	1.029	1.330	2.018
	C.D. at 5 %	1.564	3.123	4.035	6.123

This criterion is crucial as weight loss has a negative impact on the visual appeal, taste, and overall weight of the fruit. The nutritional makeup of the fruit is likewise influenced by PLW. It was noted that there was a significant decrease in weight as the fruit ripened and the concentration of ethylene gas increased. According to Kulkarni et al. (2011), the ripening process was seen to accelerate as the concentration of ethylene gas increased. This can be attributed to the heightened respiratory climacteric induced by ethylene treatments. This would have led to an increase in moisture loss from the fruits, resulting in a decrease in fruit weight relative to the control group.

The observed rise in the PLW can potentially be attributed to the ongoing physiological processes of respiration and transpiration that occur during the ripening stage. The findings align with the research conducted by Patil (2003), Mahajan et al. (2010), and Mebratie et al. (2015). Medicott et al. (1990), Montalvo et al. (2007), and Lagune et al. (2007) showed similar results in mango fruit, while Dhillon and Mahajan (2011) found similar results in pear.

7.3 Organoleptic evaluation

The organoleptic taste refers to the sensory perception and acceptability of fruits, specifically pertaining to their edible quality. Overall, the fruits exhibited a high level of acceptability until the fourth day of the therapy, after which there was a decline in their acceptability (Table 6). The treatment T3, which involved the use of 150 ppm ethylene gas, achieved the highest score of 8.0 on the 4th day of treatment. This was followed by the treatment T2, which involved the use of 100 ppm ethylene gas. On the sixth day of treatment, the highest score was observed in treatment T2, which involved the application of 100 ppm ethylene gas.

Table 6. Effect of ethylene gas on organoleptic evaluation during ripening of banana

Treatment Number	Treatments	Days after treatment			
		2	4	6	8
T ₁	50 ppm ethylene gas	5.00	6.00	7.00	3.25
T ₂	100 ppm ethylene gas	6.00	7.75	7.25	2.00
T ₃	150 ppm ethylene gas	6.00	8.00	7.00	2.00
T ₄	50 ppm ethephon	5.00	5.33	6.25	4.00
T ₅	100 ppm ethephon	5.00	5.38	6.88	4.00
T ₆	150 ppm ethephon	5.88	6.38	6.88	3.00
T ₇	Control	5.00	5.00	5.00	6.00
	S.E.±	0.13	0.17	0.13	0.12
	C.D. at 5 %	0.78	0.91	0.78	0.66

Overall, the organoleptic rating exhibited an increase until the 6th day following treatment, after which it saw a fall. This indicates that the fruits remained edible until the fourth day of the treatment. Regarding the organoleptic score, it was observed that treatment T3, which involved the use of 150 ppm ethylene gas, achieved the highest score of 8.0 on the fourth day of treatment. This was followed by treatment T2, which involved the use of 100 ppm ethylene gas. On the sixth day of treatment, the highest score was observed in treatment T2, which involved the application of 100 ppm ethylene gas. This is further demonstrated by the alteration in color of banana fruit. Nair and Singh (2003) have found similar findings in mango cv. Kensington, while Kulkarni et al. (2004) have observed similar results in mango cv. Kesar. Mahajan et al. (2010) have also reported similar results.

7.4 Color parameters.

Peel color is a characteristic and also attracts consumers to buy a product. Table 7 showed that the peel color of banana changed gradually throughout the ripening process. The color changed very fast and uniformly due to ethylene 150 ppm treatment. In the case of other treatments, color changed slowly, and color didn't form uniformly.

Table 7. Effect of ethylene gas on color parameter during ripening of banana

Treatment Number	Treatments	Days after treatment											
		2			4			6			8		
		L	a	b	L	a	b	L	a	b	L	a	b
T₁	50 ppm ethylene gas	59.5	-4.3	31.1	63.3	-2.2	33.2	65.1	0.5	35.3	66.1	2.3	37.2
T₂	100 ppm ethylene gas	57.3	-4.1	30.8	65.2	-1.1	35.9	67.8	0.9	37.8	69.1	3.5	39.7
T₃	150 ppm ethylene gas	67.8	-2.2	34.2	70.3	0.2	40.2	74.6	3.1	45.6	76.3	5.5	42.3
T₄	50 ppm ethephon	61.2	-5.7	32.2	64.7	-2.9	34.2	66.8	0.2	35.6	68.7	2.1	37.3
T₅	100 ppm ethephon	63.9	-4.5	31.7	65.9	-0.9	34.9	67.4	0.2	37.4	68.9	3.1	38.5
T₆	150 ppm ethephon	64.7	-4.7	34	68.7	-0.5	38.5	71.3	1.1	43.4	73.4	4.3	41.2
T₇	Control	55.1	-7.8	33.1	60.3	-4.3	35.1	63.1	-0.6	37.1	65.2	0.9	39.1
	S.E.±	1.37	3.12	1.06	1.05	1.06	1.05	0.65	0.78	3.12	1.06	1.37	1.05

This has been extensively reported by researchers such as Rao et al. (1971), Patil (2003), Mahajan et al. (2010), Tapre and Jain (2012), and Mebratie et al. (2015). According to Reyes and Paul (1995), the ripening process may cause a change in colour because of the synthesis of carotenoids and the concurrent loss of chlorophyll.

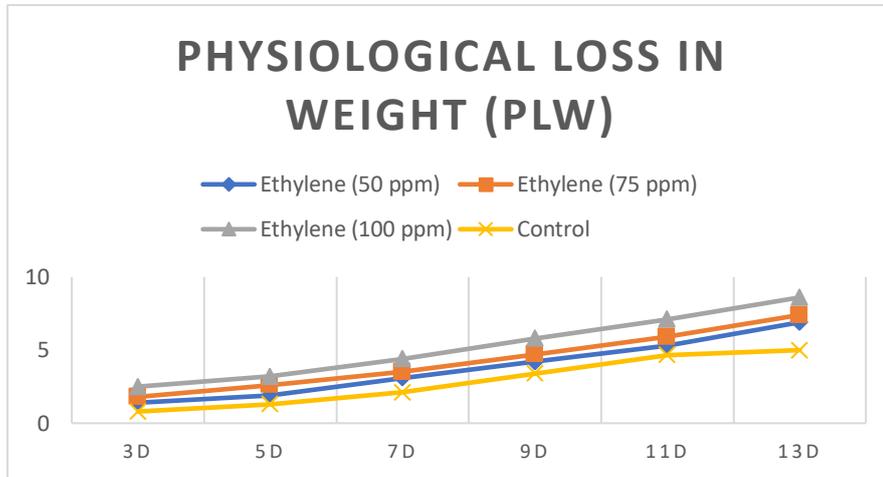
7.5 Physiological parameters of tomato after the treatment of ethylene gas

7.51 Physiological loss in weight (PLW)

The ripening treatments exhibited notable variations in Physiological loss in weight (PLW) (Figure 1), which generally increased over the ripening period. The plant leaf weight (PLW) of the tomato fruit exhibited a positive correlation with the concentration of ethylene throughout the ripening process. The untreated fruits exhibited the lowest mean PLW (2.99%), which was statistically significant when compared to the treatments administered with ethylene gas. Conversely, the fruit treated with 100 ppm ethylene exhibited the greatest average PLW (5.82%), followed by fruit treated with 75 ppm ethylene (5.64%) and fruit treated with 50 ppm ethylene (4.91%). Significant findings were observed in the interaction between treatment and ripening duration. The results indicated that untreated (control) fruits exhibited the least weight loss, ranging from 0.80 to 5.00% over a ripening period of 3 to 13 days. In contrast, fruits treated with ethylene 100 ppm showed a weight loss ranging from 2.23 to 8.60% within the same time frame.

Figure 1. Effect of ethylene gas on PLW evaluation during ripening of tomato

As the quantities of ethylene increased, there was an observed increase in the percentage of fruit



ripening. This can be attributed to the rise in the respiratory climatic conditions. Consequently, the fruits experienced a greater loss of moisture, resulting in a higher weight loss compared to the control group. The observed rise in weight loss throughout the ripening process of tomato fruits when exposed to ethylene gas may be attributed to an increase in the fruits' respiration rate (Mutton, 1978). The ripening phase of banana fruits resulted in an elevation in weight loss, which was attributed to the presence of ethylene or its derivatives (Mahjan et al., 2010).

7.5.2 Ripening

An examination of the data reveals a positive correlation between the ripening % and the concentration of ethylene. The post-harvest administration of ethylene enhances ripening by binding ethylene to a receptor, resulting in the formation of an activated complex. This complex triggers many physiological reactions, including ripening (Yang, 1980). According to Bal and Kok (2007), the application of ethylene or its analogs after harvest has been found to enhance the ripening process in tomato, mango, guava, and kiwi fruit.

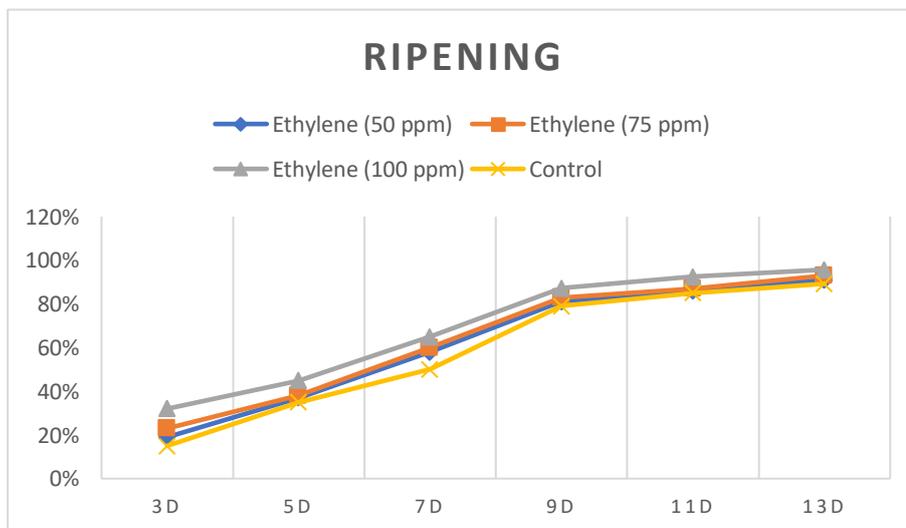


Figure 2. Effect of ethylene gas on percentage of ripening of tomato

Upon examination of the data, it is evident that there is a positive correlation between the concentration of ethylene and the ripening percentage. The augmentation of ripening through the post-harvest application of ethylene can be attributed to the interaction between ethylene and a receptor, resulting in the formation of an activated complex. This complex then triggers a diverse range of physiological reactions, including the process of ripening (Yang, 1980). The application of ethylene or its analogs after harvest has been found to improve the ripening process in tomato, mango, guava, and kiwi fruit (Bal and Kok, 2007).

7.5.3 Total Soluble Solids (TSS)

The total soluble solids (TSS) of tomato were affected by several treatments (Table 7). The average total suspended solids (TSS) concentration of the fruits treated with ethylene gas was found to be the highest at 4.84%, followed by the fruits treated with 100 ppm ethylene at 4.80%. These two treatments exhibit substantial differences from one another. The control fruits exhibited the lowest mean total soluble solids (TSS) content, measuring at 4.63%. Additionally, it was noted that the total soluble solids (TSS) content exhibited a gradual and consistent increase across all treatments throughout the ripening phase. Overall, none of the therapies showed a statistically significant difference in terms of TSS. Significant variations were noted in the ripening period, namely up to the 11th day of ripening. An upward trend in the average total soluble solids (TSS) was noted as the ripening period progressed, namely from 3.73 to 5.25% during a timeframe of 3 to 13 days. There was no significant interaction observed between the treatments and the ripening period.

Table 7. Effect of ethylene gas on TSS evaluation during ripening of tomato

Treatment	3D	5D	7D	9D	11D	13D	Mean	LSD (p = 0.05)
Ethylene (50 ppm)	3.83	4.37	4.70	5.07	5.27	5.30	4.76	Treatment (T)= 0.08 Storage periods (S)= 0.12 T x S= NS Initial value of total soluble solids at harvest = 3.45%
Ethylene (75 ppm)	3.53	4.37	4.73	5.03	5.27	5.22	4.69	
Ethylene (100 ppm)	3.60	4.63	4.97	5.27	5.29	5.30	4.84	
Control	3.80	4.10	4.60	4.90	5.17	5.23	4.63	
Mean	3.73	4.38	4.77	5.09	5.26	5.25		

The rise in total suspended solids (TSS) levels observed throughout the ripening process can be attributed to an elevation in the concentration of organic solutes due to the loss of water. The rise in fruit production may also be attributed to the multitude of anabolic and catabolic processes occurring, which prepare the fruit for senescence. The rise in total soluble solids (TSS) can be ascribed to the process of water loss and the hydrolysis of starch and other polysaccharides, resulting in the formation of soluble sugars. The average total suspended solids (TSS) was found to be lowest in untreated fruits and highest in the ethylene gas (100 ppm) treatment. The statistical analysis revealed that there was no significant interaction between the treatments and the ripening period. Bal and Kok (2007) reported same findings in tomato, pear, guava, and peach.

7.5.4 Ascorbic acid

The different treatments exhibited a notable disparity in relation to ascorbic acid (Table 8). The concentration of ascorbic acid exhibited an upward trend as the ripening period progressed. The ethylene gas (100 ppm) treatment exhibited the highest mean ascorbic acid content (19.04 mg/100 g fruit weight), while the untreated (control) fruits displayed the lowest mean ascorbic acid content (14.88 mg/100 g fruit weight). A substantial interaction was seen between the therapy and ripening duration. The fruits subjected to ethylene gas treatment on the 13th day of ripening exhibited the maximum

concentration of ascorbic acid (25.69 mg/100 g fruit weight), whereas the control fruits displayed the lowest value (11.68 mg/100 g fruit weight) on the 3rd day of ripening.

Table 8. Effect of ethylene gas on ascorbic acid during ripening of tomato

Treatment	3D	5D	7D	9D	11D	13D	Mean	LSD (p = 0.05)
Ethylene (50 ppm)	7.13	8.36	10.44	11.26	13.58	12.08	10.48	Treatment (T)= 0.22 Storage periods (S)= 0.26
Ethylene (75 ppm)	7.30	8.64	9.27	10.51	12.93	13.82	10.41	
Ethylene (100 ppm)	7.90	8.45	9.52	11.78	13.02	15.27	10.99	Initial value of total soluble solids at harvest = 6.25mg/100g
Control	6.59	7.33	8.54	9.80	11.67	12.30	9.37	
Mean	7.34	8.30	9.51	10.91	12.82	13.50		T x S= NS

The highest recorded value of ascorbic acid was observed in the treatment involving ethylene gas at a concentration of 100 ppm, following a ripening period of 13 days. The observed elevation in ascorbic acid levels can be ascribed to the heightened production of certain metabolic intermediary compounds, which facilitated the increased synthesis of the precursor compound of ascorbic acid. According to Gonzalez (1998) and Novelo (1998), the application of ethylene resulted in an observed elevation in the ascorbic acid content of tomatoes. Novelo (1998) has documented comparable findings in the context of guava.

7.5.5 Lycopene content

Upon examining the data, it was seen that the lycopene content had a positive correlation with the duration of ripening, as indicated in Table 9. All the treatments exhibited a statistically significant variation in terms of lycopene concentration. The ethylene gas (100 ppm) treatment had the highest mean lycopene concentration (10.99 mg/100g fruit weight), while the control fruits displayed the lowest mean lycopene content (9.37 mg/100g fruit weight). A substantial interaction was seen between the therapy and ripening duration. The concentration of lycopene exhibited an upward trend as the period of fruit ripening increased.

Table 9. Effect of ethylene gas on lycopene content during ripening of Tomato

Treatment	3D	5D	7D	9D	11D	13D	Mean	LSD (p = 0.05)
Ethylene (50 ppm)	7.13	8.36	10.44	11.26	13.58	12.08	10.48	Treatment (T)= 0.22 Storage periods (S)= 0.26
Ethylene (75 ppm)	7.3	8.64	9.27	10.51	12.93	13.82	10.41	
Ethylene (100 ppm)	7.90	8.45	9.52	11.78	13.2	15.27	10.99	Initial value of total soluble solids at harvest = 6.25mg/100g
Control	6.5	7.3	8.54	9.8	11.67	12.3	9.37	
Mean	7.32	8.3	9.5	10.91	12.82	13.5		T x S= NS

The maximum lycopene content was observed in all the ethylene gas (100 ppm) treatments. The untreated (control) fruits recorded minimum lycopene content during the ripening period. Similar results were also observed in tomatoes (Novelo, 1998).

Conclusion

Ultimately, the comprehensive data, considering physical, biochemical, and PLW examinations, demonstrates that treatment T3, which involves subjecting banana fruits to 150 ppm ethylene gas, exhibited superiority across most of the examined characteristics. Furthermore, it was noted that the treatment (T3) exhibited a consistent golden color and the maximum edible quality on the fourth day of ripening. Moreover, the utilization of ethylene for the purpose of artificially ripening fruits is authorized according to the FSSA (Anon. 2006). Hence, subjecting bananas to ripening using 150 ppm ethylene gas in an affordable ripening chamber at a temperature of 200°C and a relative humidity of 85-90% for a duration of 36 hours is a harmless method of ripening bananas.

An analysis was conducted on the color, texture, and flavor parameters of fruits at various stages of development, ranging from mature green to senescent. The treatment has a notable impact on the color development of fruits. The study revealed that subjecting tomato fruits to ethylene gas treatment at a concentration of 100 ppm for a duration of 24 hours during the ripening process led to improved ripening characteristics, including a consistent red color, desirable firmness, and acceptable quality, in comparison to alternative treatments. There was no observed substantial impact on color development because of the duration of the ethylene treatment. The fruits in the control group exhibited suboptimal ripening and had a firm texture, accompanied by substandard qualitative characteristics.

In recent years, different ripening agents have been used to artificially ripen fruits. These ripening agents along with their chemical impurities are health hazardous. To understand their health effect better, it is important to study their chemical criteria, mechanisms, effects on fruit quality and nutrition value. In this article, different fruit ripening agents are discussed along with their ripening mechanisms and possible health hazard. The national and international laws and regulations available to prohibit or control artificial fruit ripening are also reported. The socio-economic issues of artificial fruit ripening were also addressed. Artificial fruit ripening is a complex issue especially in developing countries like Bangladesh and requires the combined involvement of the government agencies, policymakers, fruit-sellers, farmers, scientists, and consumers for an effective solution to this matter. Instead of generalizing the issue, it is important to assess different aspects of artificial fruit ripening, investigate standard practices and carry out extensive scientific studies to improve the situation.

8. Recommendation

Ethylene is a gaseous plant hormone that plays an important role in inducing the ripening process for many fruits, together with other hormones and signals. An unripe fruit generally has low levels of ethylene. Artificial fruit ripening is a complex issue, especially for the developing countries, where farmers apply unregulated artificial ripening techniques to satisfy local and international demand. Developing countries such as India, Bangladesh, and other South Asian countries have sufficient legal framework to control artificial fruit ripening. Despite having strict laws and acts, the inclination toward the use of artificial ripening agents is dominant among farmers and the vendors. Therefore, there is a need for the policies, laws, and regulations on artificial fruit ripening to be enforced strictly. Unfortunately, there are no international regulations that manage artificial fruit ripening techniques. Unlike the developing nations, the developed countries have proper guidance for the use of ethylene as a ripening agent. These standards can be adopted by other countries or can be used to set up an

international standard under the framework of WHO/FAO. Lastly, mass awareness must be raised among farmers, sellers, and consumers regarding artificial fruit ripening and its possible health hazards. Media, lawmakers, researchers, and technology experts can play a vital role in this respect.

1. Use of carbide gas or acetylene gas is not permitted for artificial ripening of fruits under Food Safety and Standards Regulations, 2011 due to the potential health hazards.
2. Ethylene gas can be used for artificial ripening at a concentration up to 100 ppm (100 μ l/L)
3. External application of ethylene gas generated from various sources such as ethylene gas cylinders, compressed ethylene gas, ethanol, ethephon, etc. can be used on fruits to trigger the ripening process in fruits.
4. Any source of ethylene gas coming in direct contact with fruits is not permitted.
5. Consumers should purchase fruits from known sellers/reputed stores/dealers who declare that fruits sold have not been ripened using harmful/banned chemicals.

9. Policy Recommendation

1. One artificial fruit ripening directive (SoP) to be developed for the stakeholders of fruit business.
2. Importing Ethylene gas for fruit ripening should be included in SRO of the NRB of Bangladesh so that pure ethylene gas, ethylene sachet can be imported by the traders.

10. উপসংহারঃ

Ultimately, the comprehensive data, considering physical, biochemical, and PLW examinations, demonstrates that treatment T3, which involves subjecting banana fruits to 150 ppm ethylene gas, exhibited superiority across most of the examined characteristics. Furthermore, it was noted that the treatment (T3) exhibited a consistent golden color and the maximum edible quality on the fourth day of ripening. Moreover, the utilization of ethylene for the purpose of artificially ripening fruits is authorized according to the FSSA (Anon. 2006). Hence, subjecting bananas to ripening using 150 ppm ethylene gas in an affordable ripening chamber at a temperature of 200°C and a relative humidity of 85-90% for a duration of 36 hours is a harmless method of ripening bananas. An analysis was conducted on the color, texture, and flavor parameters of fruits at various stages of development, ranging from mature green to senescent. The treatment has a notable impact on the color development of fruits. The study revealed that subjecting tomato fruits to ethylene gas treatment at a concentration of 100 ppm for a duration of 24 hours during the ripening process led to improved ripening characteristics, including a consistent red color, desirable firmness, and acceptable quality, in comparison to alternative treatments. There was no observed substantial impact on color development because of the duration of the ethylene treatment. The fruits in the control group exhibited suboptimal ripening and had a firm texture, accompanied by substandard qualitative characteristics.

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তারিখঃ


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