Asian Australas. J. Food Saf. Secur. 2025, 9(2), 57-66; https://doi.org/10.3329/aajfss.v9i2.85299

Asian-Australasian Journal of Food Safety and Security
ISSN 2523-1073 (Print) 2523-2983 (Online)
https://www.ebupress.com/journal/aajfss/

Article

Exogenous ethylene for uniform mango ripening in low-cost ripening chamber

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Received: 01 September 2025/Accepted: 20 November 2025/Published: 30 November 2025

Abstract: Demand for ripe fruit, especially mango, is increasing around the world due to its nutrients and delicious taste attributes. But commercial handling of mangoes fruits meets challenges due to irregular fruit ripening. A practical solution to tackle this issue could be the application of external ethylene to the physiologically matured mango fruit for its climacteric nature of respiration and ethylene rate. This study aimed to figure out the optimum ethylene concentration for mature mango uniform ripening and its efficacy on the fruit quality with shelf life. Ethylene works as a catalyst to accelerate ripening processing of climacteric fruits. Therefore, exogenous concentration liquid ethylene was applied on 'BARI Aam-2' mangoes at low-cost fruit ripening chamber where ethylene gas was released from a portable ethylene generator (Catalytic Generators, USA) into a ripening chamber. Physiologically matured mango (BARI Aam-2) was collected from Bagha at Rajshahi and uniform with defectless were randomly selected for experimentation. To ensure uniform ripening, ethylene was applied per liter capacity for specific durations such as 1 min (50 ppm), 2 min (100 ppm), and 3 min (150 ppm) with concentrations verified using a gas analyzer (IAQ22080143). Among them, mango treated with 100 ppm to 150 ppm ethylene accelerated the highest peak of respiration indicating accelerated metabolic activity, while membrane permeability increased over time. Fruit firmness declined across all treatments, with similar softening levels by Day 8. The total soluble solids (TSS) levels peaked at 100 ppm and 150 ppm treatments, enhancing sweetness and carbohydrate metabolism. The study concludes that 100 ppm ethylene optimally balances ripening, sweetness, and nutrient preservation while minimizing weight loss. This application of optimum exogenous ethylene effectively regulated the ripening process of physiologically matured mango, with moderate concentration promoting desirable ripening as per the market demand and maintaining postharvest quality which ensure the produce safe for consumption.

Keywords: maturity; climacteric fruit; portable gas generator; respiration; total soluble solids

1. Introduction

Mango *(Mangifera indica* L.*)* is one of the popular fruits for its taste, rich flavor and nutritional value and it has numerous functions for its various phytonutrients and possesses the status of 'the king of fruits' (Yahia *et al.,* 2023). Because of climacteric nature of mango, both respiration rate and ethylene production increase during ripening process (Li *et al*., 2022). The production nature of ethylene in the climacteric fruits has been well established (Abeles *et al.,* 1992). This gaseous hormone is a key regulator for fruit ripening, initiating a complex cascade of physiological and bioactive compound changes that lead to fruit softening, color, and aroma development (Tipu and Sherif, 2024). It is naturally occurring plant growth regulator that significantly affects the growth, development, and shelf-life of different horticultural and ornamental crops. It is highly potent, functioning effectively at extremely low concentrations ranging from parts per million to parts per billion (Asrey *et al.*, 2023).

Ripening climacteric fruits and damaged tissues generate ethylene in sufficient quantities to influence surrounding tissue. In most plant tissues, ethylene inhibits its own synthesis. However, in climacteric fruits, as ripening begins, this inhibition shifts to a positive feedback loop, leading to autocatalytic ethylene production and a rapid increase in ethylene levels (Yinglin and Wang, 2023).

The application of exogenous ethylene is a common postharvest practice to accelerate ripening in climacteric fruits. By manipulating ethylene levels, it is possible to synchronize ripening, reduce postharvest losses, and improve fruit quality (Akhtar *et al.,* 2010). Mangoes have several biological activities and are also considered as nutraceutical fruit (Kumar *et al.,* 2021). During ripening, mango fruits undergo a range of biochemical changes, including a rise in climacteric respiration and ethylene synthesis. Additionally, they undergo alterations in texture, carbohydrate composition, organic acid content, and phenolic compounds. The process also involves the production of volatile aroma compounds and the development of a yellow hue in the pulp (Singh *et al.,* 2013). Gallic acid is an important polyphenol found in mango pulp, along with six hydrolyzable tannins and four smaller substances (Maldonado-Celis *et al.*, 2019). Polyphenols have antioxidant properties which contribute to prevent against cardiovascular and cancer (Murillo, 2017).

The plenty of β-carotene exists in mango fruits which enhance antioxidants and nutritional properties (Sivakumar *et al.,* 2011). The fruit plays a significant role in nutritional security by providing β-carotene (Takagi *et al.,* 2025). β-carotene as the primary carotenoid contains in mangoes, having vitamin A is essential for human health (vision, reproduction, immune system etc.) Membrane permeability assists as a key indicator for measuring the extent of ripening and softening in living tissue. This can be evaluated by measuring the percentage of electrolyte leakage from the tissue. Additionally, the progression of softening is closely linked to the ripening process (Ntsoane *et al.,* 2019). Fruit ripening and tissue injury are associated with alterations in cell membrane integrity and permeability. Ripening, physical damage and aging or senescence could be measure through the cellular leakage of plant tissues (Díaz-Corona *et al.,* 2020).

The quality of fruit ripened using exogenous ethylene depends on the appropriate application of optimal ethylene levels, as well as the regulation of CO_2 and O_2 concentrations, temperature, relative humidity, and duration of exposure (Lee *et al.,* 2025). Several studies have been conducted in different countries of different climates on different fruits such as mango ripening through ethylene gas exposure for 12 to 24 hrs (Kad *et al.,* 2017; Asrey *et al.,* 2023). But there is no concreate information of liquid ethylene converted to gaseous form to apply uniform ripening of specific variety with controlled temperature and humidity as commercial practice in Bangladesh. Almost every year, some farmers of mango growers or traders harvest earlier to get higher prices of immature mango and then apply different ripening chemicals or Plant Growth Regulator (PGR) like Ethephon, Ethrel, Ripen 15, Tomtom, Sea-Queen etc. as spray or dipping practice before loading mango fruit in transporting vehicle for long distance market. Immature mango fruit exhibited uneven peel color turned yellowish, and flesh became non-juicy, bitter test and less shelf life with lower quality compared to matured fruit. However, application of ethylene gas accelerates ripening of climacteric produces due to its maturity and higher amount of internal ethylene production, thus fruit attains desirable color, flavor, taste and its shelf life. It is undoubtedly true that higher amount of tree ripe fruit is not possible to receive every day at a time for fulfilling nutritional demand as per customers' requirement. In this regard, commercial technology with scientific and safe ripening practice is urgent to fulfil daily requirement of fresh ripe fruit consumption for our health. Therefore, the present research was conducted to optimize exogenous ethylene application rate for uniform ripening of mangoes (BARI Aam-2) and evaluate its effects on fruit quality attributes and develop a standardized postharvest protocol to minimize losses. The findings are expected to enhance the year-round marketability of the fruit as per consumer's demand for food and nutritional security.

2. Materials and Methods

2.1. Ethical approval

Ethical approval was not required for this study.

2.2. Collection of mango fruit

Physiologically matured mangoes (BARI Aam-2) were collected from a commercial farmer's orchard of Bagha, Rajshahi and transported by truck in the early morning to the Postharvest Technology Divisional (PHTD) Packhouse of BARI, Gazipur (Figure 1). Then infected mangoes were sorted, and uniform size (250-300 g) were selected. After that, mangoes were washed and randomly distributed for the experimentation.

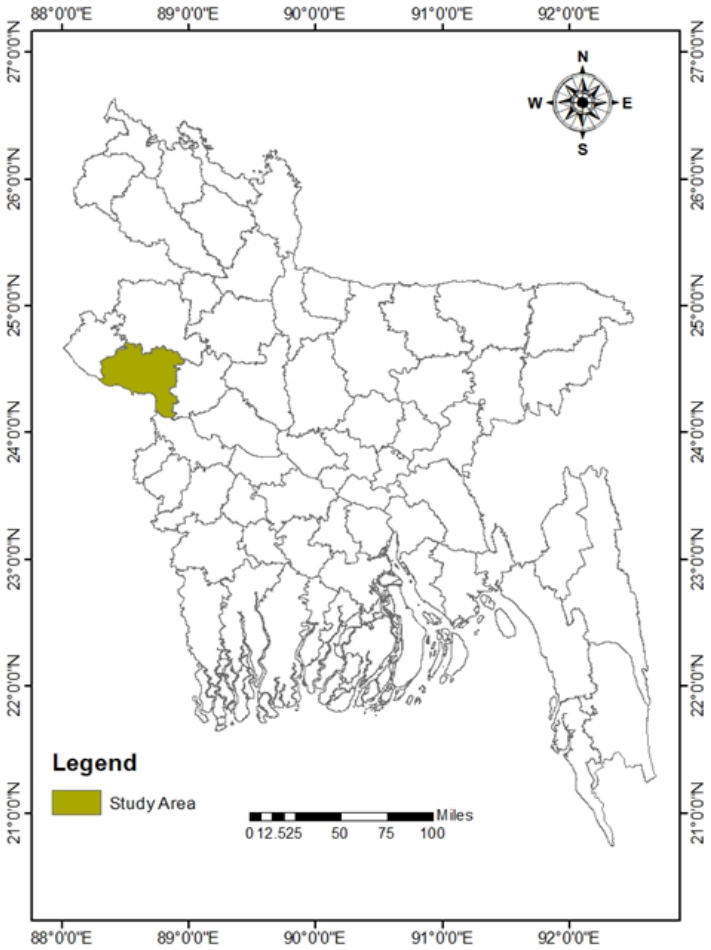

Figure 1. Mango samples were collected from Bagha, Rajshahi, Bangladesh.

2.3. Experimental design

For the experimentation, mangoes were exposed to different doses of concentrated liquid ethylene such as 0, 50, 100, 150 and 200 ppm. Mangoes were kept in plastic crates and exposed for overnight at the PHTD developed Low-cost Ripening Chamber (L 3.5m ×W 2m×H 2m). Treated mangoes were then stored at 20±2°C with 80±5% RH for 12 days to analyze physicochemical quality. Each treatment was replicated three times and standard method, and protocol were followed to record data during the study.

2.4. Evaluation of physicochemical attributes

2.4.1. Determination of respiration rate and ethylene production in treated mango

Gas chromatography was used to measure carbon dioxide, as followed by Zhang *et al.* (2011). Three to five fruits per treatment were kept in equipped 2.5 L glass jar having septa and then closed the lid for one hr maintained 20 degree C. Five milliliter samples of the headspace were taken, and analyzed the amount of CO_2 using a gas chromatograph (Varian Nexis GC-2030, Shimadzu Corporation, Japan) having a thermal conductivity detector (PTCD1, CO_2) Via an automated sample-loop and valve system. Then one milliliter

sample was passed through a porapak (3m×3 mm) [particle size 149-177 m (80/100 mesh)] columns (Varian) coupled in series to the PTCD1 for determining CO_2. The carrier gas (Hydrogen) was used 25 mL min^{-1} and 40 mL min^{-1} for reference gas (Nitrogen). Initially the injector temperature was set at 25°C where the oven temperature was maintained from 60-190°C, and 140°C was for the PTCD1. Carbon dioxide (CO_2) was measured using standard gas mixtures having 1.02% CO_2 (19.3 mg L^{-1} CO_2). The amount of respiration (CO_2) was determined using standard formula and expressed as ml CO_2/kg·hr (Devanesan *et al.*, 2011). For determination, ethylene production mango samples were placed in 2L covered with airtight cylindrical plastic containers. The produced ethylene was measured with CID CI-900RK portable ethylene analyzer after 15 min intervals up to 8 days. Ethylene was calculated and expressed as nmol C_2H_4 $kg^{-1}s^{-1}$ (Buthelezi and Mafeo, 2024).

2.4.2. Peel appearance of mango fruit

Mango peel color was assessed using a color meter (Spectrophotometer CM-5, Konica Minolta, Japan) with D65 illumination and a 10° observer angle, calibrated with white and black ceramic tiles. Color measurements (L*, a*, b*) were recorded from opposite positions of each fruit in CIE units. Hue angle (h°) = $\tan^{-1}$ (b*/a*) and Chroma (C*) = $\sqrt{(a^2 + b^2)}$ were calculated. L* represents lightness (0 = black, 100 = white), a* indicates redness (+) or greenness (−), and b* represents yellowness (+) or blueness (−). Hue angle reflects color transition from green to yellow, while chroma represents color saturation (Gill *et al.*, 2017).

2.4.3. Fruit texture analysis

For textural firmness measurement, a Digital Firmness Tester (DFT 14, Agro Technologie, France) is used following the method of Rahman *et al.* (2013). An 8 mm stainless steel flathead probe penetrated the fruit surface by 5 mm until tissue breakage. Firmness was expressed as resistance force (N).

2.4.4. Evaluation of percentage electrolyte leakage

Membrane permeability (electrolyte leakage) was determined as per the method described by Ahmad *et al.* (2016). For determining electrical conductivity (EC_a), first two-tree cubic of mango peel discs were immersed in deionized water. Then, the test tubes containing these peeled discs were placed in a water bath at temperatures between 50°C and 60°C for 25 min, after which the electrical conductivity (EC_b) of the samples was recorded. Following this, to estimate again electrical conductivity (EC_c) the tubes containing samples were dipped for 10 min in hot water at 100°C. The following formula was used to measure electrolyte leakage (%) = $(EC_b - EC_a)/EC_c \times 100$. Each experiment was repeated three times with both biological and technical replicates.

2.5. Evaluation of nutritional quality of mango fruit

2.5.1. Total soluble solids (TSS) content

TSS was observed with a digital hand refractometer (Atago, Japan) by placing a drop of pulp solution on its prism with temperature compensation and reading obtained directly from the refractometer (Rashid *et al.*, 2019).

2.5.2. Titratable acidity (TA) content

Percentage of TA was measured using 5 g of homogenized pulp sample and titrated with 0.1 N NaOH using phenolphthalein as an indicator. TA was determined as described by Ranganna (2007) and expressed as percentage.

2.5.3. Ascorbic acid content (AAC)

For AAC determination of mango, 10 g mango pulp was homogenized in 50 mL of 3% cold metaphosphoric acid (HPO_3), and then blended for 2 min. After that, pulp was filtered through Whatman No. 2 filter paper. A 10 mL aliquot was titrated with 0.1% 2,6-dichlorophenol-indophenol solution until a stable pink color persisted for 15 seconds. The solution was calibrated with an ascorbic acid standard, and results were expressed as mg per 100 g fresh weight (Ranganna, 2007).

2.5.4. Beta carotene (BC) content

BC was determined following the method of Nagata and Yamashita (1992). One gram weight of the sample was homogenized with a mixture of acetone and hexane (2:3, v/v). The upper hexane layer, containing the carotenoids, was separated and its absorbance measured at 453, 505, 645, and 663 ηm using a spectrophotometer. The β-carotene concentration was calculated using following formula:
β-carotene=0.216×A663−1.22×A645−0.304×A505+0.452×A453. The result was expressed as mg per 100 g fresh weight.

2.6. Statistical analysis

The experiment was conducted using a completely randomized design, and the data collected was inputs in MS Excel and statistically analyzed using SPSS software (version 17.0).

3. Results and Discussion

3.1. Respiration rate and exogenous ethylene production of treated mango (BARI Aam-2)

The respiration rate and endogenous ethylene production of BARI Aam-2 mangoes were significantly influenced by ethylene concentrations and storage duration (Table 1 and Figure 2). The highest respiration rates were recorded in fruits treated with 100 ppm (39.93 ± 3.93 ml CO_2 kg^{-1} hr^{-1}) and 150 ppm (39.95 ± 0.52 ml CO_2 kg^{-1} hr^{-1}) at the early stages of storage, clearly exceeding those in the control and 50 ppm treatments. This initial rise reflects the stimulation of respiratory metabolism triggered by exogenous ethylene application. By day 6, respiration in 150 ppm treated fruits declined to 56.20 ± 2.28 ml CO_2 kg^{-1} hr^{-1}, indicating a post-climacteric metabolic adjustment typical of rapidly ripening climacteric fruits. Endogenous ethylene production also displayed a concentration-dependent trend (Table 1). The 100 ppm and 150 ppm treatments produced an early and sharp increase in ethylene within 2-4 days, while the control and 50 ppm treatments exhibited a slower and more gradual rise. The temporary reduction in ethylene on day 6 followed by a secondary rise on day 8 implies a biphasic ethylene production pattern. This pattern indicates an initial autocatalytic burst driving ripening, followed by a senescence-related phase of ethylene synthesis, a behavior commonly reported in climacteric mango cultivars (Chomba *et al*., 2025). Similar ethylene-induced metabolic responses have been reported in mangoes (*Mangifera indica* L.) and other climacteric fruits, where exogenous ethylene accelerates respiration and ripening while shortening the pre-climacteric phase (Singh *et al*., 2025). The data confirms that ethylene treatment is an effective postharvest management tool to manipulate ripening rate and quality of BARI Aam-2. Optimizing ethylene concentration and exposure duration could therefore provide a practical strategy for improving market readiness, synchronizing ripening during transport, and minimizing postharvest losses in the commercial mango supply chain.

Table 1. Changes ethylene production rate (n mol/kg/s) of exogenous ethylene treated BARI Aam-2.

Treatment (Ethylene conc.)	Initially (Day 0)	Day 2	Day 4	Day 6	Day 8
0 ppm (Control)		3.86±0.04^{c}	12.28±0.20^{b}	14.08±0.06^{a}	28.66±1.67^{b}
50 ppm	3.83±0.04^{a}	5.94±0.01^{c}	27.37±2.64^{ab}	28.05±0.29^{a}	35.38±0.34^{ab}
100 ppm		29.33±0.47^{b}	33.50±0.70^{a}	27.26±0.75^{a}	52.75±1.14^{a}
150 ppm		39.91±0.54^{a}	44.75±1.30^{a}	27.45±0.75^{a}	46.39±1.30^{ab}

Values are mean ± standard deviation (n=3); Different lowercase letters in each column differ significantly among the samples (p<0.05).

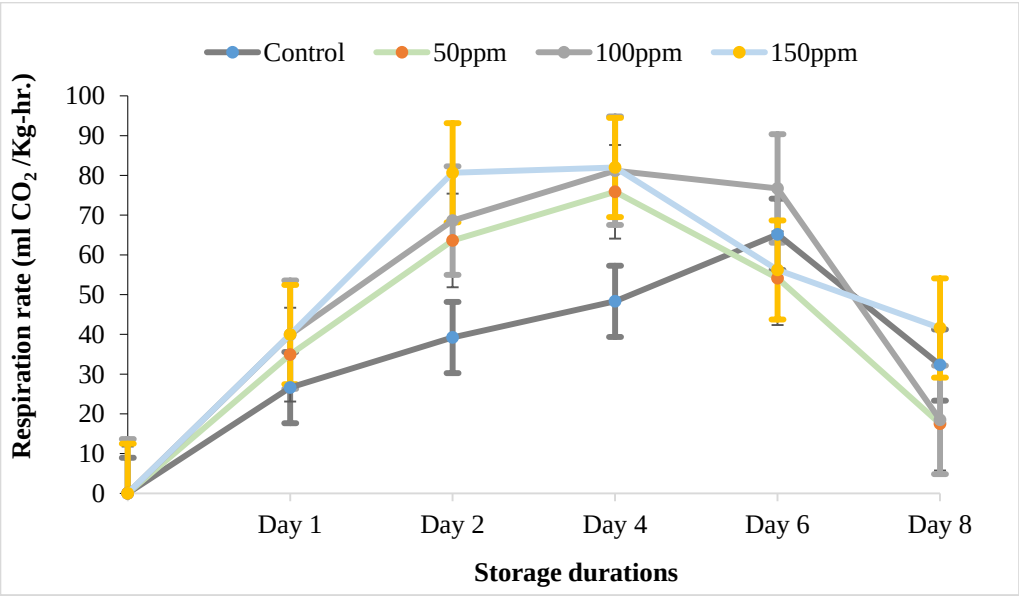

Figure 2. Changes respiration rate (ml CO_2 /Kg-hr.) of exogenous ethylene treated mango (BARI Aam-2).

3.2. Peel appearance of treated mango

Hue angle values observed a steady reduction through all treatments as ripening progressed. On day 8, the control mango fruit and the fruit treated with 150 ppm ethylene had hue angle values of 106.87 and 100.15, respectively. Mango fruit treated with 50 ppm were comparable to those of the 150 ppm-treated fruit ($p < 0.05$). Fruit treated with 100 ppm treatment differed significantly from both the control and the other treatments, with lower values indicating advanced color development toward orange. Salveit *et al*. (1999) described that the use of exogenous ethylene accelerates ripening by breaking down the green pigment while promoting the synthesis of carotenoids, leading to the development of a yellow color. All treated mangoes at the end of 8 days storage period, the treated fruits were fully ripened, while the control fruits were not entirely ripened, as some retained green covers. These findings align with reports on mangoes by Tover *et al.* (2011). It is likely that exogenous ethylene activated metabolic and carotenoid-synthesis pathways in both peel and pulp.

3.3. Fruit texture evaluation of treated mango

Mango fruit firmness varied with different ethylene concentrations, showing reduced firmness during storage between 4 to 12 days compared to other treatments. By the end of the storage period, no significant differences ($p < 0.01$) were observed across treatments, although firmness declined faster in mangoes treated with 100 ppm and 150 ppm ethylene. Control fruits initially displayed the highest firmness of 11.08 N, which steadily decreased to 9.76 N by day 4, sharply dropping to 2.53 N by day 8 and reaching 1.01 N by day 12. Fruit firmness can be influenced by exposure duration, even at very low ethylene concentrations (Schouten, 2018). Ethylene application notably impacts fruit texture, as ethylene-responsive transcription factors such as EREBP are rapidly activated by mechanical stress, triggering ethylene-responsive genes. In mangoes, elevated ethylene levels likely boost expression of these genes, accelerating softening (Li *et al.*, 2022). Research by Tipu *et al.* (2024) showed that ethylene stimulates enzymes including pectin methylesterase, polygalacturonase, and β-galactosidase, which contribute to firmness reduction. Ethylene also regulates the expansion gene (MiExpA), further aiding pulp softening. Together, these enzymes and related processes likely cause the observed firmness loss after 24 hrs treatment with 100 ppm ethylene.

3.4. Electrical leakage percentage of exogenous ethylene treated mango (BARI Aam-2)

The electrical leakage percentage in ripened BARI Aam-2 mangoes over an eight-day period indicates the extent of membrane integrity loss, a key indicator of fruit ripening and cellular degradation. Higher electrical leakage percentages reflect greater membrane disruption, which typically occurs as the fruit ripens and cells begin to lose structural integrity. There is a vibrant increase in electrical leakage from day 2 to 8. This trend reflects the natural progression of ripening, where cellular breakdown and membrane permeability rise due to enzymatic activity and biochemical changes. Control treatment presents the lowest electrical leakage throughout the storage period, beginning at 22.33% on day 2 and gradually increasing to 30% by day 8 (Table 2).

Table 2. Percentage electrical leakage of exogenous ethylene treated BARI Aam-2.

Treatment (Ethylene conc.)	Initially (Day 0)	Day 2	Day 4	Day 6	Day 8
0 ppm (Control)	20.00±1.00^{a}	22.33±1.53^{b}	23.33±0.57^{c}	27.33±0.57^{c}	30.00±1.00^{c}
50 ppm		34.00±3.00^{a}	33.00±1.00^{b}	34.00±3.00^{b}	46.33±0.57^{a}
100 ppm		37.00±2.00^{a}	39.00±2.00^{a}	45.00±1.00^{a}	47.66±2.52^{a}
150 ppm		32.33±2.52^{a}	32.33±2.52^{b}	35.66±1.53^{b}	46.39±1.30^{ab}

Values are mean ± standard deviation (n=3); Different lowercase letters in each column differ significantly among the samples (p<0.05).

Mango treated with 100 ppm ethylene has higher initial leakage (37%) compared to control, indicating less initial membrane stability. Leakage steadily rises to 47.66% by day 8, exhibited a continuous increase and signifying that 100 ppm is less effective in preserving cell membrane integrity over time. Another treatment (150 ppm treated fruits) initiates with an electrical leakage of 32.33% on day 2, the highest among the treatments initially, and increases to 46.39% by day 8. The sharp rise from day 6 to day 8 indicates that treatment, 150 ppm may lead to a quicker breakdown of cellular structures early in the storage period, with a more gradual increase from day 6 onward. That is similar for 50 ppm treated fruit. Mango fruits treated with 50 ppm ethylene gas also break down cell membrane integrity highly from day 6 to 8, that causes fruits membrane stability rapidly. Treated mango (100 ppm ethylene) exhibits the highest early leakage, which may make these treatments less suited for situations where extended freshness is required. However, they may be suitable for

applications where faster ripening is acceptable, such as for markets needing ready-to-eat mangoes (Asrey *et al.*, 2023). Emad and Khedr (2023) stated that percentage of electrical leakage increased when the mango fruit was treated with high concentrate ethylene at the end of experiments. The study indicates that leakage is closely associated with fruit ripening, particularly during the respiratory climacteric phase. Increased leakage of potassium, magnesium, and calcium can signal changes in membrane permeability, which may affect the fruit's ability to maintain its structural integrity and quality during ripening.

3.5. Nutritional attributes of exogenous ethylene treated mango (BARI Aam-2)

Table 3 indicates that mango fruit treated with 150 ppm ethylene had higher TSS levels than control fruit at the end of the experiment day 12, with the highest recorded values being 18.17^{o}B and 16.4±0.10^{o}B, respectively. It is also similar for 100 ppm treated mango fruit. TSS was comparable ameong all ethylene-treated mango fruit that were kept at normal temperature on days 4 to 8 ($p < 0.05$) but difference at day 12 ($p > 0.05$). This suggests that ethylene applied at various concentrations for 24 hrs did not prompt any significant effect on TSS (Table 3). These results were conformity by Tovar *et al.* (2011) and they found the TSS of 500 ppm concentrated ethylene treated mango fruit was 19.11 ^{o}B. Increased TSS has also been recorded by several authors concomitant with the hydrolysis of starch into glucose, fructose, and sucrose (Lee *et al.*, 2024). Ethylene may therefore be held accountable for these modifications. Due to a higher generation of autocatalytic ethylene, Table 3 indicates that the change rate on TSS of fruit treated with higher concentrate ethylene was higher than the rate of fruit treated with lower concentrate ethylene.

In case of titratable acidity (TA), 50 ppm treated fruits maintained higher acidity levels until day 8 (0.20%) but observed a decline trend by day 12 (0.05%). Because of normal process, TA had to drop due to reduction of organic acids content (Hossain *et al.*, 2014). As the mango ripened, TA dropped regularly in 100 ppm ethylene treated mango. Both control and 100 ppm ethylene treated fruit had statistically different acidity values ($p < 0.05$) and reached acidities of 0.08% and 0.11% respectively, at the end of the storage. For mango fruit treated with 150 ppm ethylene decreased considerably (0.13%) as compared to 50 ppm (0.20%) and 100 ppm (0.16%) (Table 3). TA reduced due to the availability of organic acids and inversely related to respiration (Kumar *et al.*, 2021).

Table 3. Changes physicochemical quality of BARI Aam-2 treated with exogenous ethylene at 20°C and 85% RH.

Storage (Day)	Treatment (Ethylene conc.)			
	0 ppm (Control)	**50 ppm**	**100 ppm**	**150 ppm**
	Total soluble solids (°Brix)			
0	11.23±0.20^{a}			
4	13.23±0.25^{b}	14.23±0.25^{b}	16.86±0.15^{a}	14.97±0.25^{b}
8	15.40±0.10^{b}	15.70±0.10^{b}	16.93±0.15^{a}	16.50±2.43^{a}
12	16.4±0.10^{b}	17.33±0.28^{b}	18.16±1.27^{a}	18.17±1.55^{a}
	Titratable acid (%)			
0	0.08±0.03^{a}			
4	0.11±0.01^{c}	0.15±0.01^{b}	0.17±0.05^{a}	0.12±0.01^{c}
8	0.12±0.02^{c}	0.20±0.01^{ab}	0.16±0.02^{b}	0.13±0.02^{c}
12	0.08±0.00^{b}	0.05±0.01^{c}	0.11±0.00^{a}	0.08±0.02^{b}
	β-carotene (mg/100g)			
0	7.12±0.21^{a}			
4	9.59±0.32^{c}	11.77±0.26^{b}	12.35±0.34^{a}	13.26±0.17^{a}
8	10.29±0.27^{c}	13.75±0.04^{c}	16.62±0.10^{b}	18.04±0.22^{a}
12	12.71±0.15^{b}	8.51±0.38^{c}	19.34±0.11^{a}	9.03±0.02^{c}
	Firmness (N)			
0	11.08^{a}			
4	9.76^{a}	8.78^{a}	8.40^{a}	8.27^{a}
8	2.53^{b}	1.21^{b}	1.15^{b}	1.13^{b}
12	1.01^{b}	1.00^{b}	0.99^{b}	0.98^{b}
	Hue Angle (H)			
0	108.03 ± 0.68^{a}			
4	106.87±0 .55^{a}	104.72±0 .54^{b}	104.26 ±0.06^{b}	104.56±0 .015^{b}
8	106.13±0 .15^{a}	103.82±0 .85^{b}	104.07±0 .02^{b}	102.29±0 .14^{bc}
12	106.87±0 .55^{a}	102.39±0 .05^{bc}	103.20 ±0.08^{b}	100.15±0 1.78^{c}

Means with same letters within a row are not statistically different (p<0.05). Values are mean ± standard deviation of 3 replicates.

β-carotene plays a vital role in vision and various metabolic processes. Mango pulp is a notable source of carotenoids, with concentrations varying between 0.9 mg and 9.2 mg per 100 g depending on the cultivar, geographic origin, and ripeness (Ntsoane *et al.*, 2019). β-carotene was significantly influenced by ethylene application. Fruit treated with 100 ppm ethylene exhibited the highest β-carotene levels by 12-day (19.34 mg/100g), indicating that this concentration helps maintain or enhance nutrient content. Similarly, 150 ppm maintained maximum β-carotene levels up to 8-day (Table 3). Chena *et al.* (2003) identified 25 carotenoids including all-trans β-carotene in mango pulp being the most common (29.34 μg/g). Other key carotenoids include cis-isomers of β-carotene (9.86 μg/g), violaxanthin and its isomers (6.40 μg/g), neochrome (5.03 μg/g), luteoxanthin (3.6 μg/g), neoxanthin and its isomers (1.88 μg/g), zeaxanthin (1.16 μg/g), and 9- or 9′-cis-lutein (0.78 μg/g).

4. Conclusions

Ethylene treatment effectively regulated the ripening process of mango (BARI Aam-2), with moderate concentration promoting desirable ripening and maintaining postharvest quality. The study confirmed that controlled ethylene exposure accelerates ripening while preserving sweetness and nutrient content, providing an optimal balance for optimizing storage and market readiness. Findings indicate that excessive ethylene may induce early senescence, indicating the need to refine treatment duration and concentration for better quality retention. Further research should focus on understanding the molecular mechanisms of ethylene response and its interaction with other ripening regulators to develop precise ripening management strategies for commercial applications.

Acknowledgements

The authors gratefully acknowledge the Bangladesh Food Safety Authority under the Ministry of Food, the Government of the People's Republic of Bangladesh, for providing financial assistance to conduct a research project entitled "Standardization of Ethylene Gas for Uniform Fruit Ripening in Low-Cost Ripening Chamber". The authors also thank the Postharvest Technology Divisional scientific staff of Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh, for providing technical support during the research work.

Data availability

All study results are fully reported in the text and tables of this manuscript.

Conflict of interest

None to declare.

Authors' contribution

Md. Golam Ferdous Chowdhury conducted experimental design and supervised the research activities; Robiul Islam planned and designed the experiment, analyzed the data, and wrote and edited the manuscript; Md. Hafizul Haque Khan supervised the whole research activities; Habibul Bari Shozib conducted experimental data generation using GCMS 2030; Mohammad Mainuddin Molla assisted for preparing lab protocol to analyze the samples; Md. Sarowar Kabir organized fresh sample from the field and assisted to analyze respiration and ethylene rate; Md. Aslam Uddin and Arifa Khatun primarily reviewed and edited the manuscript. All authors have read and approved the final manuscript.

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