The effect of concentrations and exposure durations of ethylene gas on the respiration rate of tomato fruit (*Solanum lycopersicum*)

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Abstract. Ethylene gas is often used in artificial ripening of fruit, including tomato. One of the physical characteristics which is influenced by ethylene application is the respiration rate. This research aimed to find out the effect of ethylene concentrations and exposure durations on the respiration rate of tomato in the ripening process. Ethylene concentrations of 100, 150, and 200 ppm and exposure time durations of 24, 48, and 72 hours were investigated in a 3x3 factorial design with three replications. Selected green mature tomatoes were exposed to ethylene gas, after being exposed were then loaded in the respirometer and stored in ambient room. Oxygen and carbon dioxide changes were monitored until the fruits were ripened. Using three-way repeated measure analysis, it was found that the interaction effect of the treatments on the respiration rate only significant for time of measurements and exposure time durations (P<0.05). These findings confirmed that exposure duration was important to be considered in the application of ethylene. It could also be reported that exposure duration of 24 hours was significantly different with 48 and 72 hours, whereas these two later exposure time durations were not different.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is a most important vegetable crop of the world including in tropical, sub-tropical and temperate areas. Worldwide tomato ranks third in area and production after potato and sweet potato but ranks first among processed vegetables [1]. Tomato is a climacteric and perishable vegetable, having respiratory peak during its ripening process [2]. Respiration is the key process which brings physiological disorders such as ripening, senescence, and degradation of chlorophyll. Respiration involving the consumption of oxygen (O₂) for oxidative break-down of organic components into simple molecules such as carbon dioxide (CO₂), water, with concurrent release of energy. The organic components broken down in this process may include carbohydrates, lipids, organic acids, fat and protein [3].

Climacteric agricultural products are commonly harvested at mature green stage. Mature green fruits also produce low amounts of ethylene, then gradually increase and may eventually ripen. Mature green fruit should be ripened for more attractive appearance to meet the consumer demand. Ripening is the final stage of fruit development which involves series of physiological and biochemical events leading to changes in color, flavor, aroma and texture that make the fruits both attractive and tasty [4]. However, natural ripening frequently results in non-uniform color, firmness, taste, and required

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relatively long time. Artificial ripening is often applied especially in large scale agricultural industry. Ethylene gas is one of the most common used in artificial ripening of fruit and has been used commercially in many countries for ripening process. General though, mature-green fruit are ethylene-treated to accelerate the ripening process. Fruits respond better to immediately ethylene application after harvest than after storage [5]. In the application of ethylene for ripening process, there are many factors influenced in that process such as ethylene concentration, exposure duration time, temperature, relative humidity, and method of applications. Further, various factors such as initial fruit maturity, temperature, relative humidity, air flow, as well as ethylene and carbon dioxide concentrations within the ripening room may all affect the rate of ripening [6].

The treatment of tomato with ethylene gas of 100 ppm for 24 hours at 20±1°C and 90-95% RH resulted in adequate ripening of tomato fruit after 9 days with uniform red color, desirable firmness, minimum rotting and acceptable quality [1]. However, there are still many discrepancies owing to the concentration, exposure duration and methods of application in the literatures. There is no quicker and simple method for uniform ripening of fruits available in the fruit industry which causes a major setback. The existing methods of ripening have their own pros and cons [6]. Therefore, further investigation dealing with the ethylene application on the ripening process is still to be considered to find the best method especially related with concentration level and duration of exposure of the ethylene gas. This research aimed to find out the effect of ethylene concentrations and exposure durations on the respiration rate of tomato in the ripening process.

2. Materials and methods

2.1. Location
This research was conducted at Laboratory of Environmental Engineering and Agricultural Building, Department of Agricultural Engineering and Biosystem, Faculty of Agricultural Technology, University of Gadjah Mada, Yogyakarta, Indonesia.

2.2. Material
The mature green tomatoes were bought from local market “Tani Organik Merapi” which originally harvested from Kopeng, Magelang, Indonesia. On arrival at the laboratory, tomatoes were then cleaned and carefully selected for their homogeneous in shape, size, and free from diseases and defects to be used as the experimental samples. The ethylene gas used in this research was pure ethylene obtained from local distributor in Yogyakarta, Indonesia. Syringe was used for injecting ethylene gas into ripening chamber. Fruit respiration was measured by applying static method respirometer and the changes of oxygen and carbon dioxide concentrations were measured using O₂ and CO₂ gas analyzer (Quantek 902D).

2.3. Experimental procedures
Selected mature green tomatoes were exposed to ethylene gas in an airtight plastic container. Ethylene concentration were injected using syringe into that ripening plastic container in accordance with the previously determined concentrations. After injection the container and the fruit were kept for certain determined exposure time duration at ambient temperature (28°C). After being treated, tomatoes were taken out from the container and then loaded into the respirometer. O₂ and CO₂ changes were monitored using O₂ and CO₂ gas analyzer every 6 hours for the first 3 days of ripening storage. In this research, actually the experiment was extended until 12 days. In the following research, applied ethylene concentrations were 100 ppm, 150 ppm, 200 ppm and the exposure time durations were 24 hours, 48 hours, and 72 hours. Three replications were used for each treatment combination. The respiration rate in O₂ consumption (RO₂) was calculated from the measured data of oxygen concentration changes in the respirometer using the following equations.
\[
RO_2 = \frac{[(YO_{2(t_0)} - YO_{2(tf)}) \times V]}{[100 \times M \times (t_f - t_i)]}
\]  

(1)

\(RO_2\) = respiration rate (\(O_2\) consumption) (ml/kg.h)

\(Y\) = volumetric concentration of \(O_2\) or \(CO_2\) (%)

\(t_i\) = initial time (h)

\(t_f\) = final time (h)

\(M\) = product weight (kg)

\(V\) = free volume or headspace (ml)

2.4. Statistical analysis

The values of \(RO_2\) were subjected to three-way repeated measure analysis of variance (ANOVA) using IBM SPSS Statistic 20 software. The first factor was the storage time, the second factor was the ethylene concentration, and the third factor was the exposure time duration. The data used for statistical analysis was the respiration rate at day 1, 2 and 3. While the means among treatments were compared using Duncan’s Multiple Range Test (DMRT).

3. Results and discussion

3.1. Oxygen and carbon dioxide changes during ripening storage

Oxygen concentration decreased during ripening storage, while carbon dioxide increased. Figure 1 shows an example of the oxygen and carbon dioxide changes during ripening storage, other similar graphs were not shown here. In the static method oxygen in the respirometer container would be continuously consumed by the tomato, as the result, the oxygen concentration would continuously decrease. During the first 100 hours of ripening, concentration of oxygen decreased for more than 50%. Fagundes et al. [7] found that the decrease of oxygen concentration of fresh cut apple stored at 2°C for the first 100 hours storage was more than 40%, and more than 50% for storage temperature 7°C.

![Figure 1. The change of oxygen and carbon dioxide in 100 ppm ethylene concentration during ripening process](image)

3.2. Respiration rate

The value of \(RO_2\) decreased during ripening storage in all of ethylene concentrations and exposure time durations (Figure 2). Decreasing respiration rate was a natural characteristic of agricultural products after harvest as the products had been in mature condition and would entering the ripening stage. It could be seen the sharp decline of the respiration rates occurred especially for the first 100 hour of ripening storage in the three exposure time durations. This phenomenon followed the change
of the oxygen concentration as previously mentioned, and this also indicated that in the ripening stage of tomato, the most crucial metabolism change might occur at the first 100 hours of ripening period.

![Graph A](image-a)

![Graph B](image-b)

![Graph C](image-c)

**Figure 2.** The change of respiration rate of RO$_2$ for (a) 24 hours (b) 48 hours and (c) 72 hours exposure time durations

Comparing these three graphs it was known that as the exposure time duration increased, the initial value of the respiration rate tended to increase. This indicated that ethylene increased the respiration rate of the product. Some researchers reported the same phenomenon as found in the research [8, 9, 10]. Further observation indicated that as the exposure time duration increased, the decline of the respiration rate become earlier. This might be caused by the fact that the age of tomato sample for 48 hours and 72 hours exposure time duration were one day and two days older than the exposure time of
24 hour, respectively. However, for the three ethylene concentrations in both the three exposure time durations, there were almost no significant difference of the respiration curve patterns. The three respiration curves were almost similar. This indicated that the effect of ethylene concentration on the respiration rate was weaker as compared to the effect of exposure time duration.

3.3. Statistical analysis
Statistical analysis using three-way repeated measure confirmed that from the results test of within subject effects, measurement time and the interaction between measurement time and exposure time duration were significantly affected the respiration rate (Table 1). Dhall and Sighn [1] also found that the interaction between treatment and ripening period was significant for some properties of tomato. Further analysis between subject effects, resulted that only exposure time duration had a significant effect on the respiration rate. Ethylene concentration and the interaction between ethylene concentration and exposure time duration had no effect on the respiration rate. These findings indicated that the only exposure time duration was the most important factor for respiration rate in the ripening process. Lobo et al. [11] also reported that there were no major differences found among the four ethylene concentrations used in banana ripening. However, it was also reported that treatment with ethylene gas (100 ppm) resulted in adequate ripening of tomato fruits after 9 days [1], but this research did not vary the ethylene concentrations.

**Table 1.** Three-way repeated measure ANOVA for the respiration rate of RO₂

| Source                                      | Type III Sum of Squares | df | Mean Square | F    | Sig. |
|---------------------------------------------|-------------------------|----|-------------|------|------|
| Measurement time                            | Greenhouse-Geisser       | 897.984 | 1.211 | 741.709 | 545.526 | .000 |
|                                             | Huynh-Feldt              | 897.984 | 1.828 | 491.271 | 545.526 | .000 |
| Measurement time × Exposure time duration   | Greenhouse-Geisser       | 12.336 | 2.421 | 5.094   | 3.747  | .033 |
|                                             | Huynh-Feldt              | 12.336 | 3.656 | 3.374   | 3.747  | .015 |
| Measurement time × Ethylene concentration   | Greenhouse-Geisser       | 1.072  | 2.421 | .443    | .325   | .765 |
|                                             | Huynh-Feldt              | 1.072  | 3.656 | .293    | .325   | .843 |
| Measurement time × Exposure time duration × | Greenhouse-Geisser       | 3.678  | 4.843 | .760    | .559   | .725 |
| Ethylene concentration                      | Huynh-Feldt              | 3.678  | 7.312 | .503    | .559   | .790 |

Further analysis was to compare the means values of the treatment combinations using DMRT (Table 2). Only exposure time duration of 24 hours was significantly different with 48 hour and 72 hours. While the two later exposure time durations were not different. This implied that as the time duration was more than 24 hours, there was effect of exposure time duration on the respiration rate. It was also shown that the exposure time duration of 24 hours had the largest mean value of the respiration rate. This indicated that the shorter the exposure time duration the higher would the respiration rate of the product during ripening storage.

**Table 2.** Means values comparison of RO₂

| Ethylene concentration (ppm) | RO₂   | Exposure time (hours) | RO₂   |
|------------------------------|-------|-----------------------|-------|
| 100                          | 12.2200* | 24                  | 13.4448 b |
| 150                          | 12.6789* | 48                  | 11.5570 a |
| 200                          | 11.7526* | 72                  | 11.6496 a |

*) Means in the same column with the same letter are not significant different from each other at P=0.05
4. Conclusion
The interaction effect of the treatments on the respiration rate only significant for time of measurements and exposure time durations. The effect of exposure time duration on the respiration rate was significant, whereas the effect of ethylene concentration was not significant. There also no significant interaction effect of ethylene concentration and exposure time duration on the respiration rate. The exposure time duration was a very important factor to be considered in the application of ethylene in tomato ripening. Based on exposure time durations, the highest average rate of respiration was for 24 hours. The shorter the exposure time duration of tomato to the ethylene gas, the higher the respiration rate of the tomato during ripening storage.

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