The effect of different time durations of ozone treatment and storage temperatures on postharvest quality of banana (*Musa acuminata*)

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Abstract. As a climacteric fruit, bananas continue to ripe after being harvested and it’s accelerated by ethylene produced by the product. The rate of ripening process greatly influences shelf life of banana. Ozone treatment and storage temperature potentially inhibit ethylene production and may lengthen shelf life. The purpose of this study was to observe the effect of different time durations of ozone treatment and storage room temperatures on the changes of peel colour, firmness, and weight loss of banana fruit. Green mature kepok bananas were used as the sample. The duration time of ozone exposure treatments used were 0 (untreated), 10, 15, and 20 minutes every day with the flow rate of 0.0279 ppm/min. While the storage temperatures used were 5, 15, and 27°C (ambient temperature). The physical qualities of the samples were measured every day for three weeks of storage. Repeated measure of statistical analysis indicated that storage time and its interaction with exposure time durations and storage temperatures were found to have significant effect on hue angle, chroma, firmness, and weight loss. It was also known that storage temperature had a significant effect on those above attributes, while exposure time duration of ozone treatment only affected hue angle.

1. Introduction

Banana is one of the top leading crops of agricultural global production. FAO (2020) indicates that average worldwide banana production rose significantly from 69 million tonnes in the 2000-2002 period to 116 million tonnes in the 2017-2019 period. In addition, banana is the fourth most consumed product in the world. Banana has a good taste and highly nutritious with high carbohydrates, proteins, potassium, and vitamins A, and C contents.

Bananas are included as climacteric fruit this means that bananas will experience the ripening period upon maturity by releasing ethylene gas after being harvested from the plant. Furthermore, the ripening period of bananas will also be accompanied by peel colour changes from green to yellow, flesh softening, weight losses, and other post-harvest qualities changes, until finally reach senescence point. The rate of changes in postharvest qualities of banana fruit affects shelf life and market value. However, banana ripes and decays rapidly at ambient temperatures, thus an appropriate post-harvest handling, therefore, is needed to preserve its qualities to create longer shelf life and increase its selling value. Several studies have applied some post-harvest treatments to fruit commodities to lengthen storage period of the fruits. It is also reported that the respiration rate of banana at 28°C (18.3 mlO₂/kg h) was two and a half times faster than at 15°C (7.6 mlO₂/kg h) storage temperature. As the lower the
respiration rate, the better quality will be preserved, this means that low storage temperature strongly increases the shelf life of banana [1]. Low temperatures can reduce respiration rate and enzyme activity, so that the quality of banana under storage was better maintained. Meanwhile, the application of ozone gas on kiwi is reported that the use of ozone-enriched cold storage markedly delayed kiwifruit ripening at 20°C compared with conventional storage [2]. The other researcher reports that short-term ozone treatments might be useful to reduce fruit damage and excessive softening, two of the main factors limiting tomato postharvest life, without negatively affecting other quality attributes [3]. Ozone treatment may inhibit ethylene gas production of the fruits. This inhibition of ethylene gas, in turn, will inhibit the ripening process of fruits. In addition, ozone treatment on agricultural products may reduce bacterial, viral, and pesticide contaminants so that the quality of food can be better maintained. The nature of ozone which is quickly disappearing in air and water causes ozone leaves no residue and safe to be used in the food industry.

Several previous studies have never been combined the effect of storage room temperature and ozone treatment on banana from tropical regions such as Indonesia. The purpose of this study was to observe the effect of different time durations of ozone treatment and storage room temperatures on the changes of firmness, weight loss, colour attributes of chroma, and hue angle on kepok bananas (Musa acuminata).

2. Material and Methods
2.1. Material
Mature-green kepok bananas as the samples were harvested from a farmstead at Kulon Progo (Yogyakarta, Indonesia) at the age of about 4 months after the blossom appears. The fruits were cleaned and sorted to find uniform weight, shape, maturity, and free from visual signals of any disease or blemishes. The selected samples were randomly divided into three different samples groups. The first group was intended for the destructive measurement of firmness consisting of 21 samples. The second group was for weight loss measurement consisting of 3 samples, and the third group was for the measurement of colour (hue angle and chroma) with 3 samples. All measurements were carried out every day for 21 days storage period.

2.2. Methods
The experiment was arranged in a completely randomized design, factorial 4 x 3 with three replications. The first factor was the ozone treatment in four different exposure time durations of 0 (untreated), 10, 15, and 20 minutes with the same flow rate every day. While the second factor was the storage temperature consisted of 5, 15, and 27°C (ambient temperature). Banana samples were loaded in plastic containers then wrapped using plastic film, and then exposed to ozone gas using ozone gas production device (Ozonizer Model PX-902) every day according to the above-determined exposure time durations. The flow rate of ozone gas treatment was 0.0278 ppm/minute. After being exposed to ozone gas, the sample containers were then stored at the above-determined temperature. Colour change, firmness, and weight loss of the sample were measured every day for 21 days storage period.

2.2.1 Post-harvest qualities evaluation
Peel colour change of the samples were measured every day using colourmeter (Sucolor, model SC-10) and described in the CIE L, a*, b* colour system. The colour measurements were taken at 3 different part of banana sample which were at the top, middle, and bottom part of the sample for compensating variation in surface pigmentation. The mean values were taken to represent the colour values of the samples. The a* and b* values obtained were then used to calculate the hue and chroma using equation (1) and (2), respectively.

\[
\text{Hue Angle} = \arctan\left(\frac{b^*}{a^*}\right)
\]

\[
\text{Chroma} = \sqrt{a^{*2} + b^{*2}}
\]
The firmness of banana samples were evaluated by compressing sample slice of banana flesh 2 cm diameter and 1 cm height on a compression testing machine which was equipped with a load cell (LGT, Type LAS-100kg) and an interface (Loadstar LV-1000) to connect to the computer. The maximum recorded force when it was failure was used in the analysis and expressed in kgf.

To determine weight loss, the weight of the samples were measured using a digital balance (Model MH-200, measurement range of 0 – 200 gr / 0.01 gr). The weight loss of the samples were determined as the difference of the initial fruit weight (IFW) to the final fruit weight (FFW) of each measurement day and expressed as the percentage weight loss (%) using equation (3).

\[
WL(\%) = \frac{IFW - FFW}{IFW} \times 100\%
\] 

(3)

2.2.2 Statistical Analysis

The data were analyzed using three-way (the factors are storage time, duration times of ozon exposure and storage room temperatures) repeated measure analysis on IBM SPSS Statistics (Trial version 25, SPSS Inc., USA) software. Sources of variation were storage time, duration times of ozone exposure (0, 10, 15, and 20 minutes), and storage room temperatures (5, 15, and 27°C). Further analysis for the means comparation was carried out using Duncan’s Multiple Range Test (DMRT).

3. Results and Discussion

3.1 Colour Changes

The colour changes expressed as hue angle and chroma of bananas samples during storage are presented in Figures 1 and 2 respectively. In general, the values of those two colour attributes tended to decrease during storage time. On the first day, the hue angle for all samples was 106.72, this indicated that the sample was still in green condition. The hue values of all samples stored at 5°C decrease more severe as compared to 15°C and 27°C, further at storage temperature of 15°C indicated the lowest decrease of hue values. This meant that storage temperature of 15°C was able to maintain the hue colour of the sample better than the others. On the other words, the storage temperature of 15°C was the most suitable temperature to preserve banana hue colour as compared to storage temperatures of 5°C and 27°C. This might be caused by the fact, that at 5°C banana experienced a chilling injury, while at 27°C storage temperature, respiration rate would be quite high which promoted faster colour changes. These findings indicated that although banana had been treated using ozone, but it was still not capable to retard chilling injury at 5°C storage temperature nor could not resist hight respiration rate at 27°C storage temperature.

Results of statistical analysis using repeated measure, it was found that from the test of within-subject effect, storage time, interaction of storage time*storage temperature, storage time*exposure time duration, and storage time*storage temperature*exposure time duration significantly affected the hue angles of the sample. While from test between subjects indicated that storage temperature, exposure time duration of ozone treatment, and the interaction of those two factors also significantly affected hue angle. This finding meant that the changes of hue angle depended on many factors including storage time, exposure time duration, storage temperature as well as the interaction between them.

Forney et al [4] reported that continuous exposure of broccoli to 200 nL·L\(^{-1}\) ozone only slightly reduced the rate of yellowing, which may be due to low ambient ethylene concentrations. Table 1, shows means comparison using DMRT for all treatment combinations. It was found that the largest hue values were dominated by storage temperature of 15°C in all of exposure time durations. This might be an indication that the best storage temperature was 15°C. However, for the exposure time duration, it was found that exposure time durations of 10 and 15 minutes significantly differed with 20 minutes, there was an indication that those exposure time durations might gave the most appropriate of the exposure time. The smallest hue angle occurred at 5°C storage temperature for all exposure time
durations, this advised that storage temperature of 5°C should not be used to store banana fruit, as at this temperature banana would experience chilling injury as stated above. It was reported that the critical temperature for occurrence of chilling injury was 5°C for ‘Prata’ banana and 10°C for ‘Nanica’ banana [5]. While, Yap et al., stated that bananas would change the color to darker when it had been over-ripening [6].

![Figure 1](image1.png)

**Figure 1.** The changes of hue angle of all samples during storage at temperature (a) 5°C, (b) 15°C, and (c) 27°C

![Figure 2](image2.png)

**Figure 2.** The changes of chroma of all samples during storage at temperature (a) 5°C, (b) 15°C, and (c) 27°C

| Treatment          | Hue Angle | Chroma | Firmness | Weight loss |
|--------------------|-----------|--------|----------|-------------|
| Exposure0-T5°C     | 54.4533a  | 8.6600a| 16.5767d | 23.3733ab   |
| Exposure0-T15°C    | 87.8233a  | 29.9833a| 8.0467b  | 27.7067b    |
| Exposure0-T27°C    | 62.6733a  | 16.6300f| 1.5800a  | 37.5300d    |
| Exposure10-T5°C    | 56.1733b  | 10.5200b| 16.4667a | 20.0567a    |
| Exposure10-T15°C   | 87.3767b  | 25.0033f| 8.9033b  | 24.1567b    |
| Exposure10-T27°C   | 66.3067d  | 19.0333d| 1.8700a  | 32.7567c    |
| Exposure15-T5°C    | 56.7533b  | 10.8767b| 16.4433d | 19.5400a    |
| Exposure15-T15°C   | 87.7933b  | 25.7800f| 9.5833c  | 21.8100a    |
| Exposure15-T27°C   | 68.3467b  | 20.5500f| 2.0167a  | 33.2300d    |
| Exposure20-T5°C    | 56.5433b  | 10.1567b| 16.5067d | 22.1800a    |
| Exposure20-T15°C   | 84.7700b  | 25.0533f| 9.7333c  | 22.9900a    |
| Exposure20-T27°C   | 67.7433c  | 21.4867c| 2.2667a  | 33.5267d    |

*)Values in the same column followed by the same letter were not significant different

Table 1. Means comparison of the evaluated attributes using DMRT

Figure 2 shows the changes of chroma of the banana samples for all treatments evaluated. The same as hue angle, the values of chroma changed along with storage time and temperatures. The storage temperature of 15°C was the best in retarding chroma values as compared to 5°C and 27°C. From the statistical analysis, it was found the same results as in the hue attribute, except there was no
significant effect of exposure time duration on the chroma value. It was also reported that there was no significant effect of storage time during cocoa fermentation on chroma but it significantly affected hue angles [7]. DMRT analysis showed that the storage temperature of 15°C dominated the largest chroma values, with the highest value was for the control. It might be caused by the stronger effect of storage temperature which suppressed the effect of ozone treatment, as the result the effect of ozone treatment did not appear. The smallest chroma values also occurred at 5°C storage temperature for all exposure time durations. This strengthen the above finding that storage temperature of 5°C should not be used to store banana fruit, as this caused chilling injury although it had been treated by ozone.

3.2 Firmness

Figure 3 shows the firmness changes for all samples at each storage temperature. It was clear that firmness of all sample decreased along with storage time, however, each storage temperature decreased in a different pattern. The storage temperature of 5°C seemed to have the smallest rate of decrease will the largest was for storage temperature of 27°C, and storage temperature of 15°C lay in between those two storage temperatures. Clearly, this indicated that storage temperature of 5°C was the best in retarding sample firmness, however as stated above this temperature produced the worse colour appearance as the result of chilling injury. For those reasons, the storage temperature of 15°C was the best choice for banana storage as compared to 5°C and 27°C.

![Figure 3. Firmness of all samples during storage at temperature (a) 5°C, (b) 15°C and (c) 27°C](image)

It was found that from the test of within-subject effects, storage time, interaction of storage time*storage temperature, storage time*exposure time duration and storage time*storage temperature*exposure time duration significantly affected the firmness values of the sample. While from test between-subjects effects was found that only storage temperature affected samples firmness. The means comparison using DMRT confirmed that the lower the storage temperature the larger the firmness values of the sample. Hence storage temperature of 5°C resulted in the largest firmness of the sample. As stated above, however, the storage temperature of 5°C caused banana to experience chilling injury resulted in worse colour appearance. Therefore, storage temperature of 15°C would be the most reasonable choice.

The results of this study were supported by Adi et al, which showed that softening of bananas occurred during storage due to the effects of moisture accumulation of the pulp, moisture loss of the peel, and increasing the total soluble solid contents [8]. These observations had been attributed to starch degradation, solubilization of pectic substances, and movement of water from peel to the pulp. In addition Han et al [9] and Souza et al [10] reported that the combination of low temperature storage and ozone treatment could maintain hardness better than the controls on mulberry and carrots. Inhibition of ozone treatment was due to the reduction of ethylene production and respiration rate which resulted in inhibition of the ripening process.

3.3 Weight Loss
Figure 4 shows weight loss for all samples, where weight loss increased in the same trend for the three storage temperatures but with little bit difference rate. Storage temperature of 27°C showed the largest weight loss, while storage temperatures of 5°C and 15°C showed almost the same value of weight losses trend along with the storage time.

![Figure 4. Weight Loss of all samples during storage at temperature (a) 5°C, (b) 15°C, and (c) 27°C](image)

Based on statistical analysis it was found the same results as in firmness where from the test of within-subject effects, storage time, interaction of storage time*storage temperature, storage time*exposure time duration and storage time*storage temperature*exposure time duration significantly affected the weight loss values of the sample. While from test between-subjects effects was found that only storage temperature affected samples weight loss. The DMRT results also showed that the lowest average weight loss occurred at 5°C, it was found that weight loss at this temperature did not differ with the storage temperature of 15°C. As the result, the storage temperature of 15°C would be the best choice, this strengthening the results obtained from the analysis of firmness and colour of the samples above. The results of this study were supported by research by Adi et al., which explained that the increase in weight loss over the storage period had been attributed to the loss of moisture (transpiration) through the stomata cells of the fruit [8].

4. Conclusion
It was found that storage time, interaction between storage time and exposure time duration of ozone application, interaction of storage time and storage temperature, and interaction of those three factors significantly affected hue angle, chroma, firmness and weight loss of the samples. The storage temperature significantly affected hue angle, chroma, firmness, and weight loss, however, the exposure time duration of ozone application and its interaction with storage temperature only significantly affected hue angles. It could also be reported that all samples stored at 5°C experienced chilling injury, characterized by dark peel colour and the lowest hue and chroma values. While storage temperature of 15°C gave the best preservation of colour, firmness, and weight loss of the samples, however, there was still difficult to distinguish clearly the effect of exposure time duration of ozone treatment.

5. References
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