Effects of Ethylene Degreening on Peel Color, Physical Quality, and Chemical Content of Ambon Kuning (*Musa acuminata* Colla)

Ardhianata Triasmoko[1], Anggoro Cahyo Sukartiko[*,1], Nafis Khuriyati[1]
[1]Department of Agroindustrial Technology, Faculty of Agricultural Technology
Universitas Gadjah Mada, Jl. Flora No.1 Bulaksumur 55281, Indonesia.
Email: cahyos@ugm.ac.id[*]

Abstract

The natural ripening of ambon kuning, a typical banana widely consumed in Indonesia, tends to produce a non-uniform yellowish peel color of the fruits. Some degreening techniques using calcium carbide or ethepon, although improving the peel color appearance, may pose a safety risk compared to ethylene degreening, a technique using ethylene gas, a gas naturally produced by the fruit. This study aimed to determine the effect of ethylene degreening on changes in peel color, physical quality, and chemical content of ambon kuning and determine the combination of treatment that produces the best results. Taguchi design, with two levels for each of the three treatment factors (ethylene gas concentrations of 185.2 and 277.8 ppm, storage temperatures of 16±1 and 29±1 °C, and gas exposure time of 48 and 72 hours) was applied to banana samples stored in a hermetic bag in a temperature-controlled container. Grey Relational Analysis (GRA) was applied to get the best results considering multiple performance measures: peel color (measured as lightness L-, green -a*-, and yellow b*-values), hardness of peel and pulp, total dissolved solids, total chlorophyll, and total carotenoids contents. The best results were obtained when degreening was carried out with a gas concentration of 185.2 ppm at a storage temperature of 16±1 °C for 48 hours.*

Keywords: *Ambon Kuning Banana, Ethylene Degreening, Grey Relational Analysis, Taguchi Method*

1. INTRODUCTION

Bananas are grown commercially in more than 130 countries during the 2015-2017 period, and Indonesia became one of the contributing countries to a total global production of 6.9% (Singh et al., 2020). Bananas are easy to find in Indonesia, with the highest production in Java, as much as 52.31% (Subdirektorat Statistik Hortikultura. 2019). Meanwhile, the amount of banana production in the Special Region of Yogyakarta, in which this research was carried out, was dominated by Kulon Progo Regency, with a total production in 2018 reaching 21,139.1 tons (Winarti, 2018). Ambon, one of the local banana types in the country, is widely demanded with an average consumption of 0.055kg/capita/week or 2.868 kg/capita/year (Komalasari, 2018.). One of the most commonly traded in fruit shops, kiosks, and traditional markets is ambon kuning (Puslitbang Hortikultura. 2005).

Bananas are generally harvested at the fully mature stage. They are still green (80-90% maturity level), and post-harvest ripening is needed to increase market capacity and ideally ripen the desired color and texture (Pongprasert and Sugaya, 2020). Artificial ripening in a storage room or container is very important to control ethylene gas concentration, exposure time, exposure temperature, fruit temperature, oxygen and carbon dioxide concentration, and relative humidity (RH) to obtain uniform fruit ripening (Siddiq et al., 2020). The artificial ripening process for ambon kuning or other bananas has also been carried out in Indonesia. Two of them were calcium carbide and ethepon. Calcium carbide or carbide (traditionally) can make the fruit tasteless and unhealthy if large quantities are used (Per et al., 2007), and is also dangerous because it contains arsenic and phosphorus hydride which can be toxic (Lustriane et al., 2018). Ethephon causes hepatoxic metabolic activity, indicating possible poisoning, which can be caused by exposure to work, lack of knowledge, insecurity, wrong sprayers, lack of protective equipment, or daily consumption (Bhadoria et al., 2018). At the same time, natural ripening without any treatment tends to produce less bright, non-uniform, and less attractive peel colors due to lack of control over the fruit influencing its ripening factors (ethylene gas concentration, exposure time, exposure temperature, O2, and CO2 concentrations, and relative humidity, etc.).

Therefore, efforts are needed to safely improve the appearance of the peel color of the fruit since the visual appearance of bananas will affect consumer purchase intentions (Symmank et al., 2018). One of the treatments that can help improve its quality is ethylene degreening. This technique consists of exposure of harvested fruit to specific concentrations of ethylene gas at a particular time and controlled temperature to enhance the external quality of the fruit by allowing the development of a distinctive color of fruit varieties (Jomori et al., 2016). Degreening will accelerate the degradation process of chlorophyll, and carotene synthesis (Conesa et al., 2014) accelerate fruit ripening, discoloration, softening, and fruit aroma development characteristics (Yahia & Carrillo-Lopez, 2018) without affecting the internal quality perceived by consumers (Morales et al., 2020).

Storage temperature for degreening bananas can range from 15°C to 29°C (Sugiyono, 2005; Aini, 1994). The exposure time of ethylene gas may start from 24 to 72 hours (Sugiyono, 2005). The dose of ethylene gas concentration that can be given is in the concentration range from 50 to 300 ppm (Aini, 1994). Many previous studies have suggested using ethylene gas concentrations starting from 100 ppm (Paull, 1996; Lohani et al., 2004; Kesari et al., 2007). Based on those previous studies, the research set two levels (low and high levels for comparison) for each factor to facilitate the experimental design to be used.

Therefore, this study aimed to analyze the effect of concentration ethylene gas, time of exposure to ethylene gas, and temperature of storage environment on physical and chemical quality changes as the response determined for ambon kuning banana. This study also aimed to obtain the best combination of degreening treatment based on the response which has been specified.

2. MATERIAL AND METHODS

2.1 Sample and Material

The sample used in this study was a mature but unripe ambon kuning banana (*Musa acuminata* Colla), cultivated in the Kulon Progo region, with an estimated harvesting age ranging from 3 to 3.5 months after blossoms. Following the Taguchi design, the samples were put into Grainpro bags, a high strength PE with a barrier layer, with a thickness of 78±10% microns, and a small size with dimensions of 40 cm x 70 cm. Ethylene gas was then injected into the air-tight bag containing samples. The composition of the ethylene gas used was 10% ethylene and 90% nitrogen, following the current market-provided industrial ethylene gas ratio. Changes in peel color, physical qualities, and chemical contents were observed in response.

In addition to using literature studies, a preliminary experiment was also carried out on samples using the exact bag specifications and composition of ethylene gas, with variations in storage temperature and exposure time, to observe changes in sample peel color. It showed that brown spots begin to appear, the fastest on the 6th day and the longest on the 10th day, as a baseline for determining the storage temperature, exposure time ranges, and duration of observation in this experiment.

2.2 Factors, Levels, and Orthogonal Arrays

The experiment was designed following a 3-factor Taguchi design, each with two levels, with a range of ethylene gas concentration, storage temperatures, and exposure times, taking the results of previous experiments into account. The experiment was carried out with two replications. An experiment at least uses two replications (Krishnaiah and Shahabudeen, 2012). Factors and levels of the treatments are shown in Table 1.

Table 1. Factors and Levels of Treatments

Factors	Treatment	Level 1	Level 2
A	Ethylene concentration (ppm)	185.2	277.8
B	Storage temperature (°C)	16±1	29±1
C	Exposure time (hours)	48	72

The Orthogonal Array (OA) was determined after determining factors and levels in treatment to determine the number of experiments to be carried out. The orthogonal array matrix was selected based on the calculated degrees of freedom value. The orthogonal array design chosen by $L_8(2^3)$ is shown in Table 2.

Table 2. Orthogonal Array (OA) $L_8(2^3)$

Experiments	A	B	C
I	1	1	1
II	1	1	2
III	1	2	1
IV	1	2	2
V	2	1	1
VI	2	1	2
VII	2	2	1
VIII	2	2	2

There were eight experimental combinations based on the Taguchi method with specific treatments in this study. Besides, one control experiment without treatment was also added, and the result is depicted in Fig. 1 to 8, symbolized as K.

2.3 Response Parameters

The treatment effects were measured on various parameters, i.e., fruit peel color, physical qualities, and chemical contents. While peel color was determined as lightness L*, green -a*, and yellow b* values, physical attributes of the sample were determined as the hardness of samples peel and flesh, and the samples total dissolved solids. Chemical contents were measured as total chlorophyll and carotenoids.

Peel Color. Referring to the research (Xie and He, 2018), (Hou et al., 2015), (Gomes et al., 2013), measurement of the samples peels color in this study was described using the CIELab color scale and measured with Chromameter Konica Minolta CR-400.

Hardness. The FHT 200 model Fruit Hardness Tester, equipped with an 8 mm flat probe in newtons (Amin et al., 2015), was used to determine the hardness of the sample.

Total Dissolved Solids. As much as 10 to 15 g of mashed banana was mixed with 40-50 ml distilled water. The mixture was then filtered and taken a few drops for measuring the TSS value with an ABBE Atago Japan refractometer (Ali et al., 2018) (Lustriane et al., 2018), (Sanaeifer et al., 2016).

Total chlorophyll and carotenoids. Referring to the Arnon method (Hendry and Grime, 1993) using 80% of acetone, 1 g sample was extracted with 20 ml of acetone, then measured by a UV-Vis spectrophotometer with the Jenway 6305.

2.4 Data Analysis

Referring to Krishnaiah and Shahabudeen (2012), the data were analyzed in the sequence of stages as mentioned below.

Calculation of Means Factor Effects. Each response was averaged against each factor at all levels.

Analysis of Effect Factor S/N Ratio (Signal to Noise Ratio). Based on the quality target value to be achieved, the larger - the better characteristic type was used for the response parameters: lightness value (L*), yellow value (b*), total carotenoids, and total dissolved solids. Meanwhile, the smaller - the better quality characteristics were used for the degree of green value (-a*), total chlorophyll, and the level of fruit hardness.

Analysis of Variance. ANOVA was performed for the three factors with each parameter response.

Best Combination with Grey Relational Analysis. The Taguchi method was developed only to determine the best characteristics in a single response (Singh et al., 2018). Therefore, Grey Relational Analysis (GRA) was applied to get the best results considering multiple performance measures.

3. RESULT AND DISCUSSION

A total of eight experiments with Taguchi were carried out with two replications and observed for ten days. It was calculated, plotted visually, and analyzed later with Grey Relational Analysis (GRA) to determine ethylene degreening combination with the best result.

3.1 Analysis of Changes in Peel Color, Physical Qualities, and Chemical Contents

Fruit Peel Color Development. During ten observation days, peel lightness and yellow values have increased. On the contrary, the green value has decreased (Fig. 1 to 3). The results might result from the higher concentration of applied ethylene.

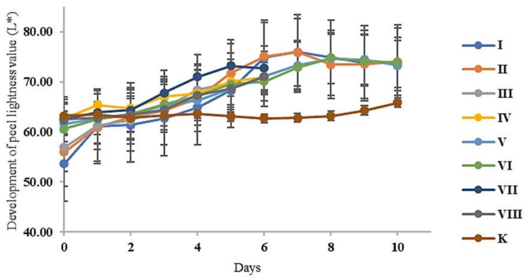

Figure 1. Development of Peel Lightness Value (L*)

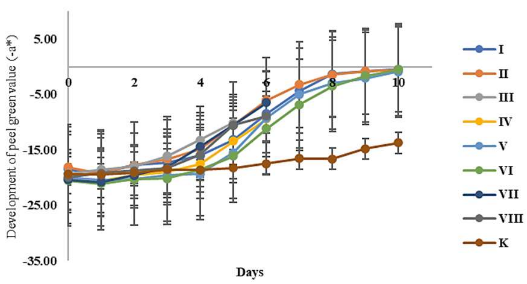

Figure 2. Development of Peel Green Value (-a*)

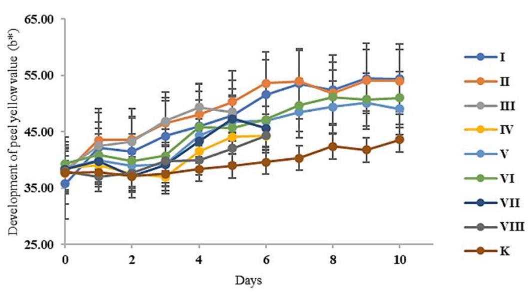

Figure 3. Development of Peel Yellow Value (b*)

The lightness value of bananas will still increase despite the high and low concentrations of ethylene gas given (Belew et al., 2016). The ethylene concentration accelerates the uniformity of fruit color (Conesa et al., 2014). In addition to the concentration of ethylene gas, prolonged exposure to the gas will also help accelerate the uniformity of the fruit's skin color. Mayuoni et al. (2011) research regarding degreening on navel oranges, star ruby, and satsuma showed that the more extended ethylene gas was exposed (72 hours), the faster the skin color turned yellow evenly.

The lightness peel value (L*) was analyzed with mean and S/N ratio. Both showed the same results, second level for factor A and first level for factors B and C, as the optimum condition. ANOVA test results on the mean and S/N ratio showed the same results. Factor B significantly affects the lightness value and contributed around 78.52% and 81.28%. On the contrary, factors A and C were not significant.

The peel green value (-a*) was analyzed with mean and S/N ratio. The optimum condition, analyzed with the mean factor, was found at the second level of factor A and the first level of factors B and C. In contrast, the optimum condition analyzed with the S/N ratio was found at the second level of factors A and B and the first level of factor C. The results of the ANOVA test on the mean and S/N ratio showed the same results that factor B had a significant effect on the response and contributed around 94.14% and 97.73%, while factors A and C were not.

The peel yellow value (b*) was analyzed with mean and S/N ratio. The optimum condition, analyzed with the mean factor and S/N ratio, showed the same results. The optimum condition was found at the first level of all factors, A, B, and C. The ANOVA test results on the mean and S/N ratio showed the same results. Factor B significantly affected the response and contributed around 40.42% and 69.98%, while factors A and C were not.

The Hardness of Peel and Flesh. During ten observation days, the hardness level of the peel and flesh of the samples have decreased, as depicted in Fig. 4 and 5. This decrease might result from changes in the composition of the dissolving cell wall pectin during fruit ripening (Soltani et al., 2011).

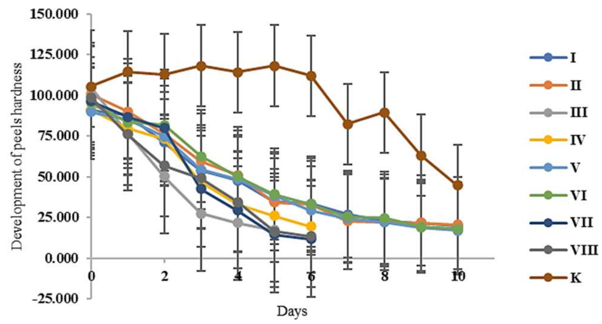

Figure 4. Development of Peels Hardness

The result showed that the banana peel has a lower hardness or softness at higher temperatures or room temperature. The value of fruit peel hardness stored at a temperature of 20°C to 22°C was higher than 28°C (Opara et al., 2012). In the research of Saraiva et al. (2018), types of *Thap Meo* bananas with ethylene gas at different concentrations showed that the parameters of fruit hardness were influenced by the high and low concentrations of ethylene gas injected. However, both were exposed for 48 hours. The higher the concentration of ethylene gas injected, the faster the ripening of the fruit so that the bananas will soften quickly.

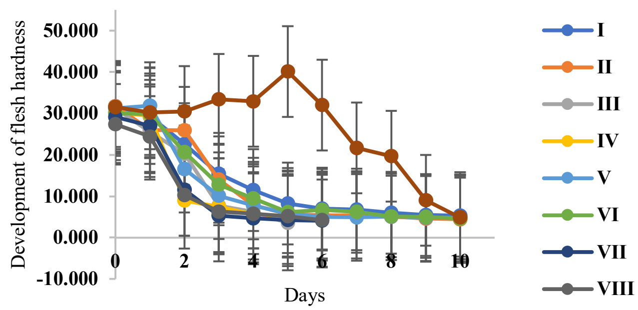

Figure 5. Development of Flesh Hardness

Changes in the fruit peel hardness level were analyzed with mean and S/N ratio. The optimum condition, analyzed with the mean factor, showed that the optimum condition was found at the second level of factors A and B and the first level of factor C. On the contrary, the optimum condition analyzed with the effect of the S/N ratio was found at factors A and B level 1 and C level 2. The ANOVA test results on the mean and S/N ratio showed that factors A and B have a significant effect, whereas factor C has not. They contributed around 47.64% and 47.46% for factors A, 33.72 % and 35.35% for factor B.

Changes in the fruit flesh's hardness level were analyzed with mean and S/N ratio. The optimum condition, analyzed with the mean factor, showed that the optimum condition was found at the second level of factors A and B and the first level of factor C. The effect of the S/N ratio showed the optimum conditions were at the second level of factors A and C and the first level of factor B. The ANOVA results on the mean and S/N ratio showed that factor B has a significant effect and gave the exact contribution of around 54.26%. In contrast, factors A and C have not.

The Total Dissolved Solids (TSS). Total dissolved solids decreased during ten observation days, as shown in Fig. 6. Research from Saraiva et al. (2018) with ethylene gas at different concentrations (500 µLL^{-1} and 1000 µLL^{-1}) showed that the total dissolved solids parameters of the fruit were affected by the high and low concentrations of ethylene gas injected. However, both were exposed for 48 hours.

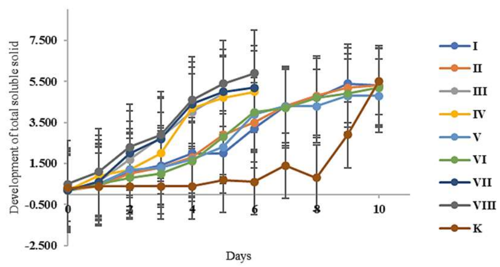

Figure 6. Development of Total Soluble Solid

Changes in the total dissolved solids content were analyzed with the mean and the S/N ratio. Both showed the same results. The best result was found at factors A, B, and C level 1. The ANOVA results on both mean factor and S/N ratio showed that factors A, B, and C have no significant effect at the 5% significance level.

Total Chlorophyll and Carotenoids. During ten days of observation, the chlorophyll content of the fruit decreased, as depicted in Fig. 7. At the same time, the carotenoid content has increased, as shown in Fig. 8.

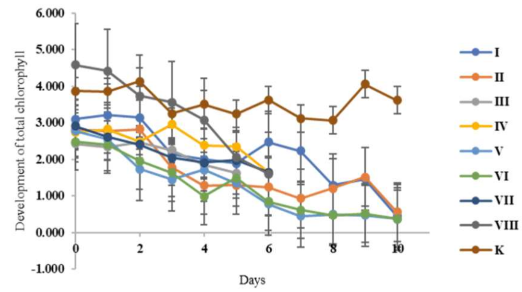

Figure 7. Development of Total Chlorophyll

Temperature plays an essential role in chlorophyll degradation. Generally, high temperature increases chlorophyll degradation, but the response of bananas to high temperatures seems relatively abnormal. Chlorophyll degradation in the skin will be inhibited at temperatures above 24°C (Yang et al., 2009). Thus, it was not surprising that the amount of chlorophyll at room temperature of 29°C, whether injected with ethylene gas or not, was still high.

Changes in the chlorophyll content of fruit peels were analyzed with the mean and the S/N ratio. The optimum condition, analyzed with the mean factor, were met at the second level of factor A and the first level of factors B and C. On the contrary, the optimum condition, analyzed with the S/N ratio, were met at the first level of factor A and the second level of factors B and C. The ANOVA results on both the mean and S/N ratio showed that factor B has a significant effect and factors A and C are not significant. It contributes around 93.30% and 96.93% at the 5% significance level.

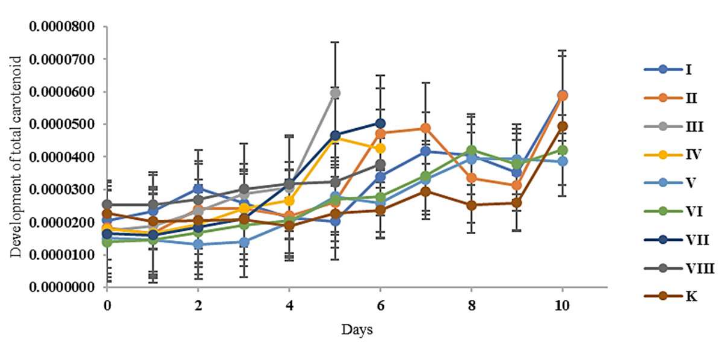

Figure 8. Development of Total Carotenoid

Changes in the carotenoid content in fruit peels were analyzed using the mean and S/N ratio factors, showing the same optimum conditions at factors A, B, and C at level 1. The ANOVA results on the mean and S/N ratio also showed that Factor A has a significant effect and factors B and C have not, thus contributing around 53.57% and 55.99% at the 5%

significance level.

Based on ten observation days, experiments 3, 4, 7, and 8, stored at room temperature, could only last for 5-6 days before they started to rot. On the contrary, experiments 1, 2, 5, and 6, stored at chilling temperature, could last up to 10 days until the observation was complete.

3.2 Grey Relational Analysis (GRA)

Since the Taguchi method was developed only to determine the optimum characteristics for a single response (Singh et al., 2018), Grey Relational Analysis (GRA) was applied to get the best results considering multiple performance measures. The stages in which data processing was carried out (Krishnaiah and Shahabudeen, 2012; Singh et al., 2018) are as follows:

Stage 1: Calculation of each response's S/N Ratio (Yij) value according to the desired quality characteristic. The results of the S/N ratio calculation are shown in Table 3.

Stage 2: Normalization of the S/N Ratio value. The normalization results of the S/N ratio are shown in Table 4.

Table 3. The Ratio Value of Each Process

L*-value	-a*-value	b*-value	Total chlorophyll	Total Carotenoid	TSS	Hardness of Peel	Hardness of Flesh
37.61	6.78	34.71	6.91	-84.62	14.65	-25.94	-14.53
37.61	6.62	34.67	5.07	-84.66	14.48	-26.21	-13.03
36.88	-20.09	33.86	-4.28	-84.50	13.80	-24.66	-11.06
37.03	-19.50	33.02	-4.33	-86.63	13.98	-25.74	-12.79
37.50	1.65	33.99	8.63	-87.90	13.62	-24.64	-13.55
37.48	6.27	34.33	8.57	-87.28	14.32	-25.15	-13.32
37.31	-16.24	33.64	-4.47	-85.61	14.30	-21.38	-12.19
37.02	-18.96	32.92	-4.19	-88.51	15.41	-22.54	-12.60

Table 4. Normalization of S/N Ratio

L*-value	-a*-value	b*-value	Total chlorophyll	Total Carotenoid	TSS	Hardness of Peel	Hardness of Flesh
1.00	0.00	1.00	0.13	0.97	0.57	0.94	1.00
1.00	0.01	0.98	0.27	0.96	0.48	1.00	0.57
0.00	1.00	0.52	0.99	1.00	0.10	0.68	0.00
0.20	0.98	0.05	0.99	0.47	0.20	0.90	0.50
0.85	0.19	0.60	0.00	0.15	0.00	0.68	0.72
0.81	0.02	0.79	0.00	0.31	0.39	0.78	0.65
0.58	0.86	0.40	1.00	0.72	0.38	0.00	0.33
0.20	0.96	0.00	0.98	0.00	1.00	0.24	0.45

Stage 3: Calculation of the Grey Relational Coefficient (GC) from the normalized S/N ratio value. The results of the GC calculation for each response are shown in Table 5. While Δ is the absolute difference between Yoj and Yij, Yoj is the optimum performance value or the superior value of response normalization, and λ is the differential coefficient of 0-1 (generally, 0.5 is used).

Stage 4: Calculation of the Grey Relational Grade (Gi) using the average Grey Relational Coefficient (GC) value combined for all responses. The results of the Gi calculation for each response are shown in Table 6.

Table 5. Normalization Results of Grey Relational Coefficient (GC) Calculation

L*	(-a)	(b)	Total chlorophyll	Total Carotenoid	TSS	Hardness of Peel	Hardness of Flesh
1.00	0.33	1.00	0.37	0.94	0.54	0.90	1.00
1.00	0.33	0.95	0.41	0.92	0.49	1.00	0.54
0.33	1.00	0.51	0.97	1.00	0.36	0.61	0.33
0.38	0.96	0.35	0.98	0.49	0.38	0.84	0.50
0.76	0.38	0.55	0.33	0.37	0.33	0.61	0.64
0.73	0.34	0.70	0.33	0.42	0.45	0.69	0.59
0.54	0.78	0.45	1.00	0.64	0.45	0.33	0.43
0.38	0.92	0.33	0.96	0.33	1.00	0.40	0.47

Table 6. Normalization Results of Grey Relational Grade (Gi) Calculation

Grey Relational Grade
0.760
0.705
0.640
0.609
0.498
0.532
0.578
0.601

Table 7. The Best Combination of Factors and Level

Level	Factor		
	A	B	C
1	0.679	0.624	0.619
2	0.552	0.607	0.612
Delta	0.127	0.017	0.007
Rank	1	2	3

Once the Grey Relational Grade (Gi) value was obtained, the best combination of factors and levels could be determined. The results are shown in Table 7. The optimal combination with the Taguchi-Grey Relational Analysis (GRA) method was at factors A level 1, B level

1, and C level 1. The best combination results that have been given to the sample are shown in Fig. 9.

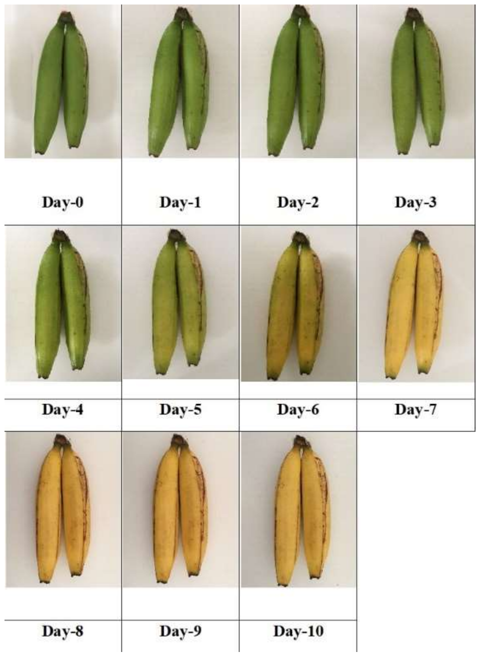

Figure 9. Appearance of the Samples with the Best Degreening Treatments

4. CONCLUSIONS

Two of the three studied degreening factors, ethylene concentration, and storage temperature, partially affected sample quality parameters. The concentration of ethylene gas significantly affected changes in sample peel hardness and its total carotenoid content. Meanwhile, storage temperature significantly affected development in ambon kuning peel color (both lightness L*, green -a*, and yellow b* values), peel and flesh hardnesses, and its total chlorophyll content. The best results were obtained when degreening was carried out with a gas concentration of 185.2 ppm at a storage temperature of 16±1 °C for 48 hours.

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