Modified Atmosphere Packaging and Heat Treatment for Maintaining the Quality of Fresh-cut Pineapple (*Ananas comosus*)

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Abstract. The research aimed to determine the effect of modified atmosphere packaging (MAP) and heat treatment to maintain the quality and prolong the shelf life of fresh-cut pineapples (*Ananas comosus*). The fresh-cut pineapples of cultivar “Queen” and “Cayenne” were treated with four treatments, namely (P1) MAP with 70% argon gas (Ar) and heat treatment at 40°C for 5 min, (P2) heat treatment at 40°C for 5 min, (P3) MAP with 70% Ar, (P4) Control. All treatments were stored in a cooler at 10°C and measurements of physical (firmness) and chemical (total phenol, total sugar and titratable acidity) were performed on 0, 2, 4, 6, 8 and 10 days of storage. Each treatment was replicated three times and the results were analyzed using Completely Randomized Design (CRD). The results showed that the application of MAP and heat treatment either combined or individually was able to maintain the quality and prolong the shelf life of fresh-cut pineapple in both cultivars.

Keywords: MAP, argon, heat treatment, fresh-cut pineapple

1. Introduction

Pineapple fruit (*Ananas comosus* (L.) Merr.) is one of the most widely consumed fruits in Indonesia and its processed products are an important export commodity. According to data from the Indonesian Central Statistics Agency [1], Indonesian pineapple production increased in 2018 by 1,805,506 tons compared to 2017 production of 1,795,985 tons and 2016 as much as 1,396,153 tons. Generally, pineapples are consumed fresh, but peeling the pineapple skin takes time and is impractical [2]. Fresh-cut pineapple is more desirable because it is considered more practical than whole pineapple. However, this pineapple fresh cut product has a shorter shelf life of only 1-2 days at room temperature, mostly limited by off-flavor and off-odor from physiological and microbial processes [3]. Many efforts have been made to prevent damage to post-harvest fruit, ranging from storage at low temperatures, modification of the atmosphere in commodity packaging or MAP (Modified Atmosphere Packaging), heat treatment (heat treatment), washing fruit with disinfectant solutions, to choosing the right packaging.
Over the decades, the use of MAP has increased. MAP is reported as one of the postharvest approaches that have a positive impact on fruit quality and safety, making it as an important contribution to extending shelf life and improving the quality of various post-harvest fruits [4, 5, 6, 7, 8, 9]. MAP is a technology that can manipulate the oxygen composition down to make respiration slower in fruit [10, 11], reducing moisture loss from products [12]. Rocculi et al. [13] studied the effect of Argon (Ar) gas content on unconventional MAP combinations (65% N₂O, 25% Ar, 5% CO₂, 5% O₂) by combining treatment with 0.5% acid solution immersion, ascorbate, 0.5% citric acid and 0.5% calcium chloride for 3 minutes that can maintain fresh quality and secondary metabolite content in apples for 12 days. MAP is often combined with cold storage to optimize in maintaining the freshness of fresh-cut fruits [14]. The use of heat treatment also extends the shelf life of fruits and vegetables. Studies from [15] showed the effect of MAP with argon gas 90% and nitrogen dioxide gas in maintaining secondary metabolites and firmness of fresh-cut kiwi. Prasad et al. [16] indicated that immersing bananas at 40°C for 5 min was able to inhibit microbial growth and delay ripening. The study aimed to assess the use of MAP with argon gas and combined with heat treatment at 40°C for 5 min in maintaining the quality of fresh-cut pineapple cultivar “Cayenne” and “Queen”.

2. Materials and Methods
The pineapples cultivar “Cayenne” and “Queen” were obtained from orchard and chose from the same grade (size and maturity). The pineapples were then washed and cleaned. After cleaning, the fruit was cut and treated according to the treatments. The treatments were (P1) MAP with 70% Ar and heat treatment at 40°C for 5 min, (P2) Heat treatment at 40°C for 5 min, (P3) MAP with 70% Ar, and (P4) Control. The samples were then stored in a cooler with a temperature of 10°C for 10 days and analysis were conducted on days 0, 2, 4, 6, 8 and 10. The observed parameters included firmness, titratable acidity, total phenol and reducing sugar.

2.1. Analysis of Physical Firmness
Firmness test was conducted to determine the level of hardness change in fresh-cut pineapple during observation. The firmness of fresh-cut pineapple measured using a penetrometer (Lutron, FR-5120, USA) every two days for ten days of storage at 10°C. The tip of the penetrometer was inserted in different parts of each sample and the firmness was calculated from the average of the measurements. The procedure was repeated three times for each treatment.

2.2. Analysis of Chemical Parameters
2.2.1. Total Soluble Solids. Three samples were chosen randomly and were used in the total soluble solids’ analysis. The samples were mashed using a mortar and were taken via pipette for transfer to the handheld digital refractometer (ATAGO, Tokyo, Japan). This analysis was conducted after the fresh-cut pineapples were stored at 10°C after storage days of 0, 2, 4, 6, 8, and 10. The total mass solids were reported in the percentage Brix unit.

2.2.2. Titratable Acidity. An analysis of titratable acidity was conducted to investigate total organic acid in the sample. The titratable acidity measurement was conducted as previously done by [17]. The mashed samples from total soluble solids were measured into 5 grams and inserted into a 100 mL volumetric flask. The flask was filled with water to the mark and stirred until homogenous. The solution was filtered, and 10 mL of the filtrate was transferred in an Erlenmeyer. Two to three drops of indicator phenolphthalein (PP) were dripped into the solution before titration with NaOH 0.1 N was conducted. The measurement was done once every two days while the fresh-cut pineapples were stored at 10°C.

2.2.3. Reducing Sugars. The reducing sugar analysis on fresh-cut pineapples used the Nelson-Somogyi (NS) method. The NS method used Nelson solution and standard sugar solutions to determine the equation for reducing sugar in the calculation of reducing sugar. The reducing sugar analysis was carried
out by mixing 1 gram of sample with 100 ml of distilled water and shaking it until it was homogeneous. After that the sample solution is filtered using filter paper and take 0.1 ml of the filtrate. The filtrate is mixed with 0.9 ml of distilled water and 1 ml of Nelson solution in a test tube. After that, the mixed filtrate was put into a water bath with a temperature of 70°C for 20 minutes. Then let stand for 30 minutes, then add 1 ml Arseno and 7 ml distilled water and shaken until homogeneous. After homogeneity, the absorbance measurement was carried out with a spectrophotometer (Thermo, Genesis 30, USA) with a wavelength of 540 nm.

2.3. Data Analysis
This study was compiled based on a Completely Randomized Design (CRD) with a single factor design. All data were analyzed using Duncan’s multiple range test with a significant level of ≤ 0.05.

3. Results and Discussion
The firmness of “Cayenne” and “Queen” cultivars was measured using a hand penetrometer and the results showed that both cultivars have the same rate of decrease in firmness during storage (Fig. 1 and 2). Meanwhile treatments with MAP and heat treatment both or individually slowdown degradation in cell wall and this was shown in significantly in Queen cultivar (Table 1 and 2).

Figure 1. Firmness of fresh-cut pineapple “Cayenne” cultivar. P1: Heat treatment 40°C for 5 min and MAP with Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

Table 1. Firmness of fresh-cut pineapple “Cayenne” cultivar. P1: Heat treatment 40°C for 5 min and Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

| Treatment | Days |
|-----------|------|
|           | 0    | 2    | 4    | 6    | 8    | 10   |
| P1        | 0.83b| 0.74b| 0.73ab| 0.77a| 0.65a| 0.64a|
| P2        | 1.04ab| 1.02a| 0.78a| 0.62b| 0.62a| 0.63a|
| P3        | 0.94ab| 0.83ab| 0.70ab| 0.64b| 0.54b| 0.60a|
| P4        | 1.12a| 0.84ab| 0.68b| 0.58b| 0.54b| 0.56a|

Numbers followed by the same letter in one column show no significant difference based on the DMRT results at the 5% level.
Figure 2. Firmness of fresh-cut pineapple “Cayenne” cultivar. P1: Heat treatment 40°C for 5 min and MAP with Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

Table 2. Firmness of fresh-cut pineapple “Queen” cultivar. P1: Heat treatment 40°C for 5 min and Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

| Treatment | Days   |
|-----------|--------|
|           | 0      | 2     | 4     | 6     | 8     | 10    |
| P1        | 0.93 a | 0.76 a| 0.72 a| 0.71 a| 0.65 a| 0.63 a|
| P2        | 0.88 a | 0.76 a| 0.74 a| 0.7 a | 0.623 a| 0.57 ab|
| P3        | 0.95 a | 0.82 a| 0.79 a| 0.68 a| 0.647 a| 0.51 b|
| P4        | 0.88 a | 0.73 a| 0.71 a| 0.64 a| 0.59 a | 0.42 c|

Numbers followed by the same letter in one column show no significant difference based on the DMRT results at the 5% level.

The firmness of the fruit is greatly influenced by pectin. Pectin consists of homogalacturonan, rhamnogalacturonan I, and rhamnogalacturonan II which are found in the middle lamella, which is between the cell walls. One of the functions of pectin is to strengthen the bonds between one cell wall and another cell wall and during the senescence process it will be degraded into pectic acid so that the firmness of the fruit decreases. The enzymes that cause cell wall degradation are polygalacturonase and pectin methyl esterase [18] and heating cause the inactivation of the two enzymes so that the firmness of the cell walls can be maintained. In addition, MAP with Ar gas inhibit the rate of oxygen movement, so that the fruit respiration rate is slowed down thus it explained why the combination of those two treatments affected in maintaining cell wall firmness. A similar thing was found in fresh-cut Kiwi [15, 19] and fresh-cut peaches [20] as well as whole peaches [21].

The results showed that during storage there was an increase in the titratable acidity (Figure 3 and 4). The increase in titratable acidity is inversely proportional to the fruit firmness for both cultivars. The phenomena also found by [22], that when the decrease of firmness is low, it increases the level of acidity. Combination of MAP treatment and heat treatment both and individually gave a significant difference to the increase in the total acid titrated during storage in pineapple (Table 3 and 4). This is because MAP suppresses fruit respiration and results in an increase in total acid. Similar results were also found in figs where MAP suppressed the respiration rate during storage [23].
Figure 3. Titratable acidity of fresh-cut pineapple “Cayenne” cultivar. P1: Heat treatment 40°C for 5 min and MAP with Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

Figure 4. Titratable acidity of fresh-cut pineapple “Queen” cultivar. P1: Heat treatment 40°C for 5 min and MAP with Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

Table 3. Titratable acidity of fresh-cut pineapple “Cayenne” cultivar. P1: Heat treatment 40°C for 5 min and Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

| Treatment | Days | 0  | 2  | 4  | 6  | 8  | 10 |
|-----------|------|----|----|----|----|----|----|
| P1        |      | 0.12b | 0.14b | 0.14b | 0.16bc | 0.14b | 0.21b |
| P2        |      | 0.13b | 0.17a | 0.14b | 0.21a | 0.18a | 0.24a |
| P3        |      | 0.10b | 0.11c | 0.14b | 0.14c | 0.18a | 0.19b |
| P4        |      | 0.16a | 0.16ab | 0.17a | 0.18b | 0.20a | 0.19b |

Numbers followed by the same letter in one column show no significant difference based on the DMRT results at the 5% level.

Sugar in fruit during storage generally increases at the beginning of the storage period and then decreases at the end of the storage period. This phenomenon was found in both cultivars as shown in Figure 5 and 6. The results also showed that the presence of MAP and heat treatment together or alone
had a significant effect on the increase of reducing sugars (Table 5 and 6). This is because the addition of Ar can suppress respiration that occurs in fruit [6]. Furthermore, the respiration rate suppressed by Ar gas treatment inhibits the degradation of complex polysaccharides into sugars. The use of MAP is known to be able to reduce the decrease in banana fruit sugar on the 12th day of storage [24]. Pinto et al. [9] added that climacteric fruits such as bananas experienced a decrease in complex polysaccharide content and an increase in total sugar during the peak of the ripening process under normal conditions.

Table 4. Titratable acidity of fresh-cut pineapple “Queen” cultivar. P1: Heat treatment 40°C for 5 min and Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

| Treatment | Days | 0  | 2  | 4  | 6  | 8  | 10 |
|-----------|------|----|----|----|----|----|----|
| P1        |      | 0.15a | 0.15a | 0.22a | 0.37c | 0.48b | 0.54c |
| P2        |      | 0.15a | 0.22a | 0.35a | 0.46b | 0.52b | 0.61c |
| P3        |      | 0.15a | 0.20a | 0.32a | 0.54ab | 0.63a | 0.74b |
| P4        |      | 0.15a | 0.22a | 0.35a | 0.56a | 0.63a | 0.86a |

Numbers followed by the same letter in one column show no significant difference based on the DMRT results at the 5% level.

Fresh cut on the fruit resulted in an increase in the activity of the phenylalanine-ammonia lyase (PAL) enzyme which also resulted in an increase in total phenol due to injury. [25, 26]. High phenol content has the potential for the browning process to be greater than low phenol content, while for the browning process to occur, PPO and oxygen enzymes must be present. The treatment given to pineapple fruit, both cayenne and queen, had a significant effect on inhibiting phenol synthesis during storage (Tables 7 and 8; Figures 7 and 8). Heat treatment can effectively deactivate the enzyme, maintain color, and fresh-cut hardness [27]. The results of other studies also showed that fresh-cut peaches that were given heat treatment at 50°C for 10 minutes had a lighter brown color and a longer shelf life [20].
Figure 6. Reducing sugars of fresh-cut pineapple “Queen” cultivar. P1: Heat treatment 40°C for 5 min and MAP with Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

Table 5. Reducing sugars of fresh-cut pineapple “Cayenne” cultivar. P1: Heat treatment 40°C for 5 min and Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

| Treatment | Days 0 | 2     | 4     | 6     | 8     | 10    |
|-----------|--------|-------|-------|-------|-------|-------|
| P1        | 2.93b  | 4.10b | 4.02bc| 3.85a | 4.12ab| 4.07b |
| P2        | 3.14b  | 4.19b | 3.64c | 4.22a | 3.81b | 4.45b |
| P3        | 3.39a  | 5.96a | 5.45a | 4.35a | 4.13ab| 5.13a |
| P4        | 2.98b  | 5.37a | 4.33b | 4.52a | 4.43a | 4.93a |

Numbers followed by the same letter in one column show no significant difference based on the DMRT results at the 5% level.

Table 6. Reducing sugars of fresh-cut pineapple “Queen” cultivar. P1: Heat treatment 40°C for 5 min and Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

| Treatment | Days 0 | 2     | 4     | 6     | 8     | 10    |
|-----------|--------|-------|-------|-------|-------|-------|
| P1        | 2.08c  | 4.26b | 2.33a | 2.81b | 3.05c | 3.39c |
| P2        | 2.28bc | 8.12a | 2.32a | 2.71b | 2.87c | 4.43b |
| P3        | 2.50ab | 2.99b | 2.75a | 2.93b | 3.91b | 4.24b |
| P4        | 2.69a  | 2.09b | 2.73a | 4.24a | 5.06a | 5.31a |

Numbers followed by the same letter in one column show no significant difference based on the DMRT results at the 5% level.

Table 7. Total phenol of fresh-cut pineapple “Cayenne” cultivar. P1: Heat treatment 40°C for 5 min and Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

| Treatment | Days 0 | 2     | 4     | 6     | 8     | 10    |
|-----------|--------|-------|-------|-------|-------|-------|
| P1        | 0.22a  | 0.16a | 0.15b | 0.15b | 0.15b | 0.14b |
| P2        | 0.20ab | 0.18a | 0.18a | 0.17a | 0.19a | 0.19a |
| P3        | 0.20ab | 0.17a | 0.17a | 0.18a | 0.19a | 0.20a |
| P4        | 0.16b  | 0.18a | 0.17a | 0.15b | 0.16b | 0.21a |

Numbers followed by the same letter in one column show no significant difference based on the DMRT results at the 5% level.
Figure 7. Total phenol of fresh-cut pineapple “Cayenne” cultivar. P1: Heat treatment 40°C for 5 min and MAP with Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

Figure 8. Total phenol of fresh-cut pineapple “Queen” cultivar. P1: Heat treatment 40°C for 5 min and MAP with Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

Table 8. Total Phenol of fresh-cut pineapple “Queen” cultivar. P1: Heat treatment 40°C for 5 min and Argon 70%, P2: 40°C heat treatment for 5 min, P3: MAP with Argon 70%, P4: Control.

| Treatment | 0    | 2    | 4    | 6    | 8    | 10   |
|-----------|------|------|------|------|------|------|
| P1        | 0.17 c | 0.15 c | 0.13 c | 0.10 c | 0.10 c | 0.10 c |
| P2        | 0.24 b | 0.15 bc | 0.18 b | 0.13 bc | 0.13 b | 0.13 b |
| P3        | 0.19 bc | 0.20 b | 0.22 b | 0.15 b | 0.13 b | 0.14 b |
| P4        | 0.30 a | 0.26 a | 0.26 a | 0.20 a | 0.18 a | 0.19 a |

Numbers followed by the same letter in one column show no significant difference based on the DMRT results at the 5% level.
4. Conclusion
MAP and heat treatment are able to maintain fruit firmness, reduce the rate of formation of reducing sugars, titratable acidity and phenolic compounds of fresh-cut pineapple both “Cayenne” and “Queen” cultivars. Furthermore, MAP treatment with 70% argon gas and heat treatment at 40°C for 5 min can maintain the firmness level and suppress the titratable acidity, reducing sugars and total phenol for 10 days of storage. These results can be used as the basis for further research regarding the chilling injury and synthesis of secondary metabolites in pineapples.

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