Kinetics analysis of the effect of storage room temperature and packaging films characteristics on the rate of change of Sugar Palm Fruit (Arenga pinata) quality in A Modified Atmospheric Packaging (MAP)

A Fatharani¹, N Bintoro¹

¹University of Gadjah Mada, Yogyakarta, Indonesia

E-mail: nursigit@ugm.ac.id

Abstract. Sugar palm fruit is a tropical fresh product which derived from sugar palm plants. Handling and storage of sugar palm fruit is still in the traditional way, and it creates difficulties for broader marketing. Storage air temperature and film packaging greatly affects to various factors of the fresh products damage that can be represented by the change in respiration rate of those products. The aim of this study was to study the effect of storage temperature and plastic film characteristics on the change of the respiration rate of sugar palm fruit during storage period in the MAP. Several treatment combinations including storage temperature and plastic film thickness were investigated in the research. It was found that storage temperature had stronger effect on the respiration rate of sugar palm fruit as compared to the effect of packaging film thickness. The higher storage temperature the longer would the time to reach constant O₂ and resulted in the higher respiration rate. Statistical analysis indicated that storage temperature, packaging film thickness, and the interaction of those two factors were significantly affect the respiration rate of the fruit. Arrhenius kinetics could explain the effect of storage temperature on respiration rate of sugar palm fruit.

1. Introduction

Sugar palm fruit (Arenga pinnata) is a tropical fresh product derived from sugar palm plants. Sugar palm fruit has the potential as a healthy food substitute for fibre and reduces blood cholesterol, but it is still lacking in postharvest handling. Most of the sugar palm still stored in the traditional way by soaking with water and replacing it every 3 days and adding additional ingredients to maintain the quality of the fruit. The traditional way of handling still makes difficulties in broader marketing, so that most of the sugar palm fruit is only sold in traditional markets. The improper fruit storage handling will damage to fruit faster. The damage can be seen from the decrease in the quality of the sugar palm fruit that has been stored for a certain period of time [1].
Figure 1. Sugar palm fruit (a) and sugar palm fruit in MAP (b)

Sugar palm fruit which has been harvested and peeled still remains alive and still continues the process of metabolism and respiration. The method for extending shelf life of sugar palm fruit is by decreasing respiration rate by adjusting the storage condition. Respiration rate is strongly influenced by the temperature of the storage space and the gas component in the storage room [2, 10]. As stated by Belay et al. [9] that low temperature might increase the storage length due to reduction of chemical reaction. Temperature also controlled enzymatic reaction which colud rise every 10°C of storage temperature. Baruipur et al. [12] also proved that product with a higher storage temperature had a shorter storage life.

Another method to extend the shelf life of fruit that has been widely approved is by using Modified Atmospheric Packaging (MAP). The mixture of gases in the package depends on the product type, packaging material, and temperature. Designing MAP should take into a steady state condition and dynamic process which depends on the product characters, its mass, atmospheric composition, film permeability, temperature, and respiration rate [8-10]. Respiration rate is a major indicator of metabolism fresh produce. Many technologies for preserving fresh produce involve respiration by Modified Atmospheric Packaging (MAP) [3].

The respiration rate will affect the quality of the physical properties of fresh products. Research conducted by Dameswari [1] proves that packaging combinations with additional materials could maintain the sugar palm fruit quality at 5°C. But in this study still use additional materials that affect the original physical properties of the product. Caleb et al. [6] have proven that storage room temperature significantly impacts the pome fruit respiration rate in MAP. Petracek [7] have examined the use of MAP to reduce water loss and protect against physical damage to sweet cherries. Good temperature regulation can also be the best tool to extend the shelf life of sweet cherries.

The effect of packaging thickness and storage temperature on the respiration rate in the sugar palm fruit is less studied. It is needed a further research on these two factors on the respiration rate of the sugar palm fruit. The aim of this research was to study the effect of storage temperature and plastic film characteristics on change of respiration rate for MAP from sugar palm fruit during the storage period.

2. Material and Methods

2.1. Product and Sample Preparation
Sugar palm fruit was obtained directly from the farmer at Kulon Progo, Yogyakarta, Indonesia. The fruits which had been picked was boiled for 30 minutes to remove the fruit latex which cause allergy, then peeled to get the fruit and transported to the laboratory. The packaging film used was a Low-Density Polyethylene (LDPE) 19.8 x 29.7 cm in size and the thickness were 30µm, 50µm, and 80µm. The fruit sample was then
filled into the LDPE plastic film and sealed, where each of packaging contained 150 g of sugar palm fruit. These samples were then stored at 5, 15 and 28°C room temperatures and measured for every certain determined period. The oxygen concentrations in all packages were measured by using O2/CO2 gas analyser (Quantek Model 902D, USA).

**Figure 2. Respiration rate measurement on MAP of sugar palm**

Measurement of oxygen concentration was carried out every 6 hours until the concentration of O2 in the package reaches a constant value. From the measured oxygen concentration, it could be analysed to find the respiration rate in oxygen consumption ($R_{O_2}$) using equation (1) when the concentration had reached a constant value [10].

$$R_{O_2} = \frac{P_{O_2} \cdot A}{100 \cdot L \cdot M} (y_{O_2}^e - y_{O_2})$$

where:
- $R_{O_2}$ = Respiration rate of oxygen (mL/kg.hours),
- $P_{O_2}$ = Permeability of plastic packaging (mL. µm/m². hour. Atm),
- $A$ = Surface area of plastic film packaging (m²),
- $L$ = Thickness of plastic film packaging (µm),
- $M$ = Weight of the product in the plastic film packaging (kg),
- $y_{O_2}^e$ = Oxygen concentration (%),
- $y_{O_2}$ = External O2 concentration (%).

**Table 1. Permeabilities of plastic film used in the research [5]**

| Thickness | $P_{O_2}$ (cm²/m².d.0,1 Mpa) |
|-----------|-------------------------------|
| 30µm      | 3304.71                       |
| 50µm      | 3196.21                       |
| 80µm      | 2584.82                       |

Arrhenius kinetics generally applies to fresh produce metabolism during the process [3]. This study used temperature variations and it was necessary to evaluate the effect of storage temperature on respiration rate, using Arrhenius kinetics equation (3).
\[ R_{O_2} = A \cdot e^{\frac{-Ea}{RT}} \]  

Where
A = Arrhenius constant (mL/kg.hours),  
Ea = Activation energy (J/mol),  
R = Universal gas constant (8,314 J/mol.K),  
T = Storage temperature (K).

2.2. Statistical Analysis
This study used factorial 3 x 3 in Completely Randomized Design (CRD) with three replications. As the first factor was the storage room temperatures of 5, 15 and 28°C, while the second factor was the plastic film thickness of 30µm, 50µm, and 80µm. The collected data were analysed using IBM SPSS Statistics 25.

3. Results and Discussion
3.1. The effect of temperature and packaging on the respiration rate

Figure 3. Changes in respiration rate at various temperatures (a) for 30 µm, (b) for 50 µm, (c) for 80 µm

Figure 3 shows the change of O₂ concentration in the packaging film for all of the three investigated plastic film thicknesses, where O₂ concentration continuously decreased and finally reached a constant
values for those three packaging film thickness. However, the time to reach the constant $O_2$ level and final $O_2$ concentration were different. The time to reach a constant, final constant $O_2$ values, and the respiration rate for the three storage temperatures and packaging film thicknesses were summarized in Table 2.

**Table 2.** Time to reach a constant, final constant $O_2$ values, and the respiration rate.

| Room temperature (°C) | Packaging film thickness (µm) | Time to constant (hour) | Constant $O_2$ (%) | Respiration rate (ml. µm/kg. hour) |
|-----------------------|--------------------------------|------------------------|--------------------|-----------------------------------|
| 5                     | 30                             | 113                    | 14.30              | 2.870<sup>a</sup>               |
|                       | 50                             | 256                    | 12.20              | 6.220<sup>f</sup>               |
|                       | 80                             | 280                    | 11.83              | 9.434<sup>e</sup>               |
| 15                    | 30                             | 109                    | 11.27              | 4.826<sup>c</sup>               |
|                       | 50                             | 134                    | 10.30              | 5.184<sup>d</sup>               |
|                       | 80                             | 182                    | 9.80               | 4.003<sup>b</sup>               |
| 28                    | 30                             | 31                     | 0.40               | 9.887<sup>h</sup>               |
|                       | 50                             | 31                     | 0.37               | 9.922<sup>b</sup>               |
|                       | 80                             | 31                     | 0.30               | 7.961<sup>i</sup>               |

It was obtained that for the same packaging film thickness as the storage temperature decrease, the time to reach constant $O_2$ increased. At storage temperature 5°C needed more than 3.5 longer time to reach a constant value of $O_2$ as compared to storage temperature of 28°C, with the constant value of $O_2$ far more higher and reached more that 35 time, whereas the respiration rate decreased around 3.5. While for the same storage temperature, it could be seen that as the film thickness increased the time to reach constant $O_2$ were also increased except for storage temperature 28°C. However the effect of storage temperature was found to be more severe than the effect of packaging film thickness.

Statistical analysis indicated that both storage temperatur, packaging film thickness, and the interaction of those two factors significantly effected the value of respiration rate of sugar palm fruit investigated (p<0.05). Respiration rate of sugar palm fruit was found to depend on many factors, and it should be carefully considered in the next research. From Duncan analysis, it could be known that storage temperature and film packaging thickness significantly different. This phenomenon was also proved by Baruipur et al. [12] that $O_2$ consumption was significantly affected by storage temperature and packaging film. Respiration rate of product with higher packaging permeability and higher storage temperature were higher than the others.

3.2. *Arrhenius kinetics*

**Table 3.** The values of collision frequency ($A$) and activation energy ($E_a$) in Arrhenius mathematical model for the three film thicknesses

| Thickness (µm) | A (mL/kg.hours) | $E_a$ (J/mol) |
|---------------|----------------|---------------|
| 30            | 22634820.305   | 36664.327     |
| 50            | 7731.823       | 16755.324     |
| 80            | 231.019        | 8527.322      |

The effect of temperature on the respiration rate of sugar palm fruit in MAP could be analysed using Arrhenius kinetics [12]. From this equation could be determined the collision frequency ($A$) and activation energy ($E_a$), as shown in Table 3. As the film thickness increased both the values of $A$ decreased
significantly, this indicated that as the film thickness increased the respiration rate would decreased. The values of these constants were then could be used to develop theoretical respiration rate prediction equations 3, 4, and 5 for the package film thicknesses of 30 μm, 50 μm, and 80 μm respectively.

\[
R_{O_2} = 22634820.305 \cdot e^{\frac{3664.327}{8.314 \cdot T}}
\]  
(3)

\[
R_{O_2} = 7731.823 \cdot e^{\frac{16755.32}{8.314 \cdot T}}
\]  
(4)

\[
R_{O_2} = 231.019 \cdot e^{\frac{8527.322}{8.314 \cdot T}}
\]  
(5)

Using those equations, the predicted respiration rates could be determined for the three film thicknesses for storage temperatures ranged from 5 to 28°C (figure 4). It was found that as the storage temperature increased the respiration rate would also increased, and as the thinner packaging film the higher would the increment of the respiration rate. Product with higher storage temperature and thinner packaging film will have higher respiration rate. It affected shelf life to become shorter due to the increase of product metabolism and spoilage organism [8, 12].

**Figure 4.** Respiration rate observations and predictions at various temperature variations

### 4. Conclusion
Storage temperature had stronger effect on the respiration rate of sugar palm fruit as compared to the effect of packaging film thickness. The higher storage temperature the longer would the time to reach constant O₂ concentration and resulted in the higher respiration rate. Statistical analysis indicated that storage room temperature, packaging film thickness, and the interaction of those two factors were significantly affect the respiration rate of sugar palm fruit (p<0.05). Arrhenius kinetics could explain the characteristic effect storage temperature on respiration rate of sugar palm fruit.

### Reference
[1] Dameswari A H, Darmawati E and Nugroho L P E 2017 Kombinasi Teknologi Kemasan Dan Bahan Tambahan Untuk Mempertahankan Mutu Kolang Kaling 5 201–8
[2] Hasbullah R 2008 Respiration Rate Measurement of Horticultural Product under Controlled Atmosphere Conditions 22 63–8
[3] Arult J, Lenckit R and Castaigne F 1995 A Review on Modified Atmosphere Packaging and Preservation of Fresh Fruits and Vegetables: Physiological Basis and Practical Aspects-Part Packag. Technol. Sci. 8 315–31

[4] Kubik L and Zeman S 2013 Determination of oxygen permeability of polyethylene and polypropylene nonwoven fabric foils Res. Agr. Eng. 59 105–13

[5] Nugrahaini A D 2019 Analisis Matematik Pengaruh Variasi Berat Oxygen Absorber dalam Kemasan dan Tebal Plastik Kemasan Terhadap Laju Respirasi dan Perubahan Kualitas Cabai Merah Keriting (Capsicum annuum L.) Selama Penyimpanan (Universitas Gadjah Mada)

[6] Caleb O J, Mahajan P V, Linus U and Withthuhn C R 2012 Postharvest Biology and Technology Modelling the respiration rates of pomegranate fruit and arils Postharvest Biol. Technol. 64 49–54

[7] Petracek P D, Joles D W, Shirazi A and Cameron A C 2002 Modified atmosphere packaging of sweet cherry (Prunus a dom L., cv. ‘Sams’) fruit: metabolic responses to oxygen, carbon dioxide, and temperature Postharvest Biol. Technol. 24 259–70

[8] Kendra K V 2010 LWT - Food Science and Technology Modified Atmosphere Packaging of Fresh Produce: Current Status and Future Needs LWT - Food Sci. Technol. 43 381–92

[9] Belay Z A, Caleb O J and Linus U 2016 Modelling approaches for designing and evaluating the performance of modified atmosphere packaging (MAP) systems for fresh produce: A review Food Packag. Shelf Life 10 1–15

[10] Fonseca S C, Oliveira F A R and Brecht J K 2002 Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packaging: a review J. Food Eng. 52 99–119

[11] Castellanos D A, Cerisuelo J P, Hernandez-munoz P, Herrera A O and Gavara R 2016 Modelling the evolution of O2 and CO2 concentrations in MAP of a fresh product: Application to tomato J. Food Eng. 168 84–95

[12] Baruipur, Cv, Sanchita Biswas Murmu and H N M 2017 LWT - Food Science and Technology Engineering Evaluation of Thickness and Type of Packaging Materials Based on the Modified Atmosphere Packaging Requirements of Guava LWT - Food Sci. Technol. 78 273–80