Modelling the effect of storage temperature on respiration rate of Pineapple (*Ananas comosus* L.) with crown

D S D Rahmadhanni, S Rahayoe, N Bintoro and Y D Prasetyatama

Department of Agricultural and Biosystems Engineering, Universitas Gadjah Mada, Jl. Flora No.1 55281 Bulaksumur, Yogyakarta, Indonesia.

E-mail: dimas.sandy.d@mail.ugm.ac.id

Abstract. Maintaining freshness and functional quality of the fruit is a challenge in the food industry since consumers demand of fresh pineapple is high. Thus, it is important to know the effect of various storage temperature on respiration rate to controlling the quality and extends the shelf-life. The respiration rate (RR) was studied over a period of storage time by treating the full crown pineapple in the storage room of 7°C, 15°C and 25°C. A closed system method was used to measure the respiration rate at 2, 4, 12, 24 hours intervals over 7,5-14.5 days of storage. Three temperature variations and three replications were carried out to observe the respiration rate. Respiration rate based on the O$_2$ consumption at 7°C is 2,05 ml.kg$^{-1}$.h$^{-1}$, at 15°C is 6,45 ml.kg$^{-1}$.h$^{-1}$ and at 25°C is 22,33 ml.kg$^{-1}$.h$^{-1}$, while based on CO$_2$ produce at 7°C is 5,90 ml.kg$^{-1}$.h$^{-1}$, at 15°C is 20,83 ml.kg$^{-1}$.h$^{-1}$ and at 25°C is 67,91 ml.kg$^{-1}$.h$^{-1}$. The modelling was conducted using Michaelis-Menten (MM) uncompetitive inhibition. The storage temperature of 7°C resulted MM constant Vmo is 4,28 and Vmc is 29,04; at the 15°C Vmo is 59,18 and Vmc is 200; and at the 25°C Vmo is 140 and Vmc is 805,10 with SSE ranged from 0,000378 to 0,0295. The Vmo-constant activation energy (Ea) is 132,42 kJ/mol and frequency factor (A) is 3E+25, while Vmc-constant Ea is 132,94 kJ/mol and A is 1,7E+26 with $R^2$ ranged from 0,82 to 0,99. The best storage temperature recomendation with distribution time more than 30 days at 12-13°C.

1. Introduction

Maintaining freshness and functional quality of the fruit is a challenge in the food industry since consumers demand of fresh pineapple is high. In 2016, a total of 26,4 million tonnes are marketed. Over the past nine years, the market has grown on average by 3.3% per year. The consumption of pineapples continues to grow, in part due to the rising income and growing population, but also to marketing campaigns focused on healthy eating. On the production side, the total volume in 2016 of worldwide is 26,67 million tonnes. Costa Rica is undoubtedly number one, with exports totalling 3.2 million tonnes or 12% of worldwide production. Next, in the top 3 are Brazil (10%), Philippines (10%) and Indonesia being number nine with 5% [1].

The postharvest of pineapple starts from harvesting, collecting, sorting, classifying, packaging, labeling, storing and distributing [2]. In general, distribution of pineapple on a local scale uses carts, motorized vehicles, boats, container trucks and trains with a delivery time of 1-4 days [3]. Distribution of pineapple for export using cargo shipping from Southeast Asia to Europe and America takes around 4 weeks while from Southeast Asia to Japan around 3 weeks, while using air cargo is less than 2 days to all region of the world [4].

The distribution process takes a long time and it causing susceptible to fruit damage. The storage technology needed for storing fruits in optimal storage conditions [5]. This process needs good handling
to prevent quality degradation such as mould, decay, shell pitting, chilling injury and internal browning [6]. Quality degradation caused by physiological process (respiration, transpiration and ethylene production) that reacting chemicals and enzyme in cells [7]. Respiration is the process of breaking down complex substrate such as carbohydrates, proteins and fats that reacting with O₂ to be a simpler component of CO₂, H₂O and energy. The respiration rate is higher if the storage temperature is higher than optimal point. It causing the fruit to rapidly decay and decrease of physicochemical quality. Thus, it needs good handling of distribution and storage processes.

Good storage technology is needed to control the optimal temperature of fruit. One of them is cold storage (CS) which is commonly used in transportation or distribution vehicles of fresh fruit storage. Operation of CS in different temperatures requires different energy loads. The lower the temperature applied, the higher the energy needs. In dealing with high cost to operating it, the application of the storage temperature does not have to be at the optimal conditions, but applies a temperature point that can control the quality of pineapple to keep fresh to consumers by taking into the distances and times of transportation or distribution.

Therefore, research needs to be done with the main focus to determine the effect of storage temperature on the respiration rate. The specific purpose of this study is to (a) analyze the effect of storage temperature on respiration rate, (b) determine the prediction of respiration rate at different temperatures by modelling using Michaelis-Menten and Arrhenius and (c) determine the best recommendation of storage temperature by knowing the shelf-life of the fruit.

2. Methodology

2.1. Experimental Procedures

2.1.1. Samples Preparation. Smooth Cayenne ‘Sunpride’ fresh pineapple fruit with crowns provided by PT. Great Giant Pineapple, Lampung, Indonesia. Product transported by refrigerated container trucks from the company until arriving for approximately 2 days. The fruit was chosen with a standard size of 3-4 (1.8-2.5 kg) and the maturity level 0-15%. The pineapples have cleaned the dirt manually with hand and duster. Each sample inserted into plastic jars as a container. In the lid portion, the jar is given the seal tape to tightening the closure. At the top of the lid, the jar is given a hole in two places and given a glue seal to ensure there is no gas leak. This hole is used to suction gas samples to be measured in a gas analyzer and as a gas return hole that has passed through the gas analyzer. After that, it is placed on a shelf in the storage room that has been conditioned. The temperature in the storage room of pineapple maintained at 7°C, 15°C and 25°C while the storage humidity maintained at 90% using thermohygrometer.

2.1.2. Mass and Volume Measurement. Weight of fruit was measured with a digital analytical scale device. The volume of fruit determined based on the fruit density by cutting the fruit flesh in a square shape with uniform size. The height, length and width of the sample measured using a ruler to calculate the sample volume and furthermore to obtained density. The density of samples used to determine the whole fruit volume. The volume of jars was measured by the water displacement method. Table. 1 showed the average values of the triplicate weight of fruit and free volume at different storage temperature variations. The free volume of the jars consisted of the total volume of the jars minus the volume occupied by their content.

| T (°C) | Weight of Sample (kg) | Free Volume (ml) |
|--------|-----------------------|------------------|
| 7      | 2.032                 | 32086.33         |
| 15     | 2.143                 | 32461.10         |
2.1. Respiration Measurement. The respiration rates of pineapple were measured using a closed system method [8-11]. The pineapple with crown was placed in polypropylene jars containing air as the initial gas atmosphere. The jars were simply closed with plastic lid with two valve for flowing the gas. Sampling of the headspace gas concentrations was terminated when constant rate period reached. Headspace O$_2$ and CO$_2$ gas concentrations in each jar were monitored using a Gasin-DH JD200 gas analyzer (Tianjin). Gas samples were taken by inserting a needle through to the first valve of the jars. Gas readings were taken continuously until constant data were displayed on the screen. To avoid modifications in the headspace gas composition and pressure due to gas sampling, a return needle was also attached to the second valve.

Typically, the samples were taken every 2 hours for first 12 hours, then 4 hours for 24 hours, then 12 hours for 5 days and finally everyday. Changes in O$_2$ and CO$_2$ concentrations were used to estimate respiration rate and modelling the respiration at another various temperature. Experiments were conducted at 7°C, 15°C, and 25°C and the sample were conducted in triplicate each storage temperature.

2.2. Mathematical Procedures

2.2.1. Respiration Rate. Respiration rate during storage time was calculated through O$_2$ consumption and CO$_2$ production measurements. O$_2$ consumption and CO$_2$ production rates were determined as [12, 13].

\[
RR = \frac{dy}{dt} \times \frac{V_f}{M}
\]  \hspace{1cm} (1)

where RR is the tissue respiration rate in O$_2$ consumption and CO$_2$ production (ml kg$^{-1}$ h$^{-1}$), dy is the changes of gas concentration (%) during the time interval as dt (h), Vf is the headspace volume (mL) and M is the sample mass (kg).

2.2.2. Respiration Rate Modelling. The respiration rate of fruit tissues refers to a global process that encompasses the diffusion of gases through the tissues as well as respiration at the cellular level [14]. Several models describe the relationship between gas concentrations and the respiration rate of fruit, although enzymatic models or Michaelis-Menten analysis have been chosen in many cases [15,16]. An uncompetitive inhibition model [17-20] was also fitted to the data to study the possible effect of CO$_2$ concentration on O$_2$ consumption.

\[
\frac{dy_{O_2}}{dt} = \frac{v_{mo} y_{O_2}}{K_m + (1 + \frac{y_{CO_2}}{K_i}) y_{O_2}} \times \frac{M}{V_f}
\]  \hspace{1cm} (2)

\[
\frac{dy_{CO_2}}{dt} = \frac{v_{mc} y_{O_2}}{K_m + (1 + \frac{y_{CO_2}}{K_i}) y_{O_2}} \times \frac{M}{V_f}
\]  \hspace{1cm} (3)

Where Vm is the maximum respiration rate, Km is the oxygen concentration at half of Vm and Ki is the dissociation constant, and o as O$_2$ and c as CO$_2$. The Equation 3 was used to estimate the model parameters by non-stiff Ordinary Differential Equations (non-stiff ODEs) 45 and fminsearch algorithm solver type using Matlab 2013a software. The solver function implements a Runge-Kutta method with a variable time step for efficient computation. The determination coefficient (R$^2$) and the sum-square of error (SSE) were calculated to evaluate the accuracy of the model. In general, the lower the SSE, the better the agreement between the experimental and predicted data [21].
The influence of storage temperatures on the respiration rate of fresh pineapple was estimated using the Arrhenius equation:

\[ k = Ae^{-\frac{E_a}{RT}} \]  

(4)

where \( k \) is the Michaelis-Menten constant, \( A \) is the frequency factor, \( R \) is the gas constant (8.314 J mol\(^{-1}\) K\(^{-1}\)), \( E_a \) is the activation energy (J mol\(^{-1}\)) and \( T \) is the absolute temperature (K). The Equation (4) can be expressed in a linear form as shown in Equation (5):

\[ \ln k = \left( -\frac{E_a}{R} \right) \times \frac{1}{T} + \ln A \]  

(5)

Next, the Arrhenius equation in each temperature variation used to predict the respiration changes during storage at 10°C, 12°C, 18°C, 20°C and 22°C by ode45 using Matlab 2013a software.

2.2.3. Recomendation Optimal Storage Condition. The results obtained from the modelling of Michaelis-Menten used to determine the best storage temperature recommendation. The changes of \( O_2 \) and \( CO_2 \) during storage evaluated by the limits of the \( O_2 \) and \( CO_2 \) that still resulted good quality. The limit is 2-5\% \( O_2 \) and 5-10\% \( CO_2 \) [22]. In this study, the limit of gas concentration was conducted to be 5\% \( O_2 \) and 10\% \( CO_2 \). The pineapple shelf-life can be determined by the respiration modelling during storage compared with the limits value. It can be recommended storage temperature by considering the storage time or distribution time which the fruit is still in good quality when received by consumers.

3. Results and Discussions

3.1. Effect of Temperature on Respiration Rate
After being harvested, the fruit is still processing the respiration. It is proven by knowing the changes of \( O_2 \) and \( CO_2 \) concentration inside the jars of pineapple. Changes in concentration under closed system conditions make the \( O_2 \) decreases and the \( CO_2 \) increases continuously to a certain period. Fig. 1a showed the change in \( O_2 \) and \( CO_2 \) during storage and Fig. 1b showed the respiration rate during storage at temperature of 7°C, 15°C and 25°C.

The results showed that changes of \( O_2 \) for each temperature variation decreased while changes of \( CO_2 \) for each temperature variation increased during storage times. Changes in \( O_2 \) and \( CO_2 \) gas occurs at the lowest rate at 7°C then medium rate at 15°C and at the highest rate at 25°C.
Figure 1. (a) Changes in gas concentrations inside closed jars containing pineapple (b) Changes in respiration rate until constant period at (○)7°C, (♦)15°C and (∆)25°C.

Table 2. Rate of O₂ consumed and CO₂ produce of pineapple in jars.

| T (°C) | O₂ consumed (ml kg⁻¹ h⁻¹) | CO₂ produced (ml kg⁻¹ h⁻¹) |
|--------|--------------------------|-----------------------------|
| 7      | 2.05                     | 5.90                        |
| 15     | 6.45                     | 20.83                       |
| 25     | 22.33                    | 67.91                       |

Table 2 showed the average respiration rate of pineapple each temperature variations. The results, appropriate with the research before [6] that the lowest respiration rate resulted at 7°C with the rate value is 2-4 mgCO₂ kg⁻¹ h⁻¹, while the medium rate resulted at 15°C with the rate value is 8-10 mgCO₂ kg⁻¹ h⁻¹ and at 23°C resulted in the highest rate is 22-30 mgCO₂ kg⁻¹ h⁻¹. The results show that at the lower storage temperature effected on the lower respiration rate. It caused by the cellular inside the fruit tissues processing the respiration slower so that the consumption rate of O₂ and production of CO₂ run slower too.

3.2. Respiration Rate Modelling

Figure 2 showed the effect of O₂ and CO₂ concentrations on O₂ consumption rate and CO₂ production rate during storage time at temperature variation. Fig. 3 showed changes in O₂ and CO₂ based on Michaelis-Menten modelling. Table 3 showed Michaelis-Menten constant each temperature variations.
The results showed that the modelling has a good fit to the observation with determination coefficient 0.82 to 0.99. Although, there was negative constant showed in Km parameter, but another research resulted in the same thing, for example research of tomatoes [23] and blueberry [24]. It is caused by the negative O₂ and CO₂ observation data. Thus, the best result with good SSE and determination coefficient is negative constant.

![Figure 2](image-url)  
**Figure 2.** Effect of O₂ and CO₂ concentrations on (a) O₂ consumption rate and (b) CO₂ production rate at (○)7°C, (◊)15°C and (∆)25°C.

![Figure 3](image-url)  
**Figure 3.** (a) O₂ consumption and (b) CO₂ production fit with a Michaelis–Menten model (continuous lines) at (○)7°C, (◊)15°C and (∆)25°C.

|        | 7°C  | 15°C  | 25°C  |
|--------|------|-------|-------|
| Vmo    | 4,2764 | 59,1755 | 139,7853 |
| Vmc    | 29,0402 | 125,002 | 805,092 |
| Kmo    | -0,7737 | -0,7677 | -1,1  |
| Kmc    | -0,0023 | -0,5595 | 0,7817 |
| Kio    | 0,0040  | 0,0038  | 0,0087 |
| Kic    | 0,0005  | 0,0058  | 0,0088 |

**Table 3** Michaelis-Menten constant at 7°C, 15°C and 25°C
Figure 4. (a) Arrhenius constant relation for model parameters of (○) Vmo, (X)Vmc, (∆) Kio and (+) Kic, (b) Linear regression relation for model parameters of (◊) Kmo and (X)Kmc.

Table. 4 Activation energy and frequency factor for the model parameters.

| k   | A       | $E_a$ (kJ/mol) |
|-----|---------|---------------|
| Vmo | 3.0E+25 | 132.42        |
| Vmc | 1.7E+26 | 132.94        |
| Kio | 1.7E+03 | 30.34         |
| Kic | 1.2E+17 | 108.32        |

Figure 4a shows the results of the Arrhenius analysis with the determination coefficient of 0.82 to 0.99. However, the negative Km value obtained by Arrhenius analysis cannot be used, thus the linear regression relation used shown in Figure 4b. The results then used to determine the Michaelis-Menten constant showed at Table. 5 and predict changes in O$_2$ and CO$_2$ during storage at 10°C, 12°C, 18°C, 20°C dan 22°C shown at Figure 5.
Figure 5. $O_2$ consumption and CO$_2$ production model at (--)$7^\circ$C, (---)$10^\circ$C, (■■)12°C, (▲▲▲)15°C, (+++)18°C, (xxx)20°C, (+++22°C and (▲▲▲)25°C.

Table 5. Michaelis-Menten constant at 10°C, 12°C, 18°C, 20°C and 22°C

| T(°C) | 10   | 12   | 18   | 20   | 22   |
|-------|------|------|------|------|------|
| Vmo   | 11,30| 16,76| 53,00| 66,97| 133,46|
| Vmc   | 50,92| 75,66| 240,29| 349,51| 607,34|
| Kmo   | -    | 0,141| 0,224|-0,373|-0,756|-0,831|
| Kmc   | -    | 0,213| 0,236|-0,306| 0,38  | 0,39  |
| Kio   | 0,002| 0,002| 0,006| 0,007| 0,008|
| Kic   | 0,001| 0,001| 0,002| 0,003| 0,005|

3.3. Recomendation Pineapple Storage

By knowing the shelf-life of pineapple at various storage temperature, it can be determined the recommend the storage temperature of pineapple. By knowing the distance and distribution time for pineapple, It can be determined the storage temperature which still presents fresh and quality pineapple.

Table 6. Shelf-life based on $O_2$ consumption and CO$_2$ produce

| T (°C) | Shelf-life (days) | \(O_2 = 5\%\) | \(CO_2 = 10\%\) |
|--------|------------------|---------------|------------------|
| 7      | ≥30              | ≥30           |                  |
| 10     | ≥30              | ≥30           |                  |
| 12     | ≥30              | ≥30           |                  |
| 15     | ≥30              | 14,17         |                  |
| 18     | ≥30              | 5,83          |                  |
| 20     | 16,66            | 3,33          |                  |
| 22     | 11,67            | 1,25          |                  |
| 25     | 1,75             | 0,83          |                  |

Based on the Table. 6 changes in CO$_2$ during storage can be stored more than 30 days at 12°C. In this research recommendation of storage temperature conducted based on changes of CO$_2$, because it is presenting better modelling and result also appropriate with references than $O_2$. That way, it can be seen that distributing pineapple with distribution time more than 30 days can used 12°C or below. But, to prevent chilling injury and other physiological disorders, unripe or partially ripe of pineapple should be stored at 10-13°C for no more than three to four weeks [6]. So, the best recommend of store the pineapple
fruit is 10-12°C. At room temperature based on CO₂ only has a shelf-life of 0.83 days. That way, storage during transportation that does not use CS technology and has a storage temperature of 25°C must be sent less than that time. So, the pineapple fruit present the freshness and good quality.

4. Conclusions
Pineapple with crown has the lowest respiration rate at 7°C the rate is 2.05 mlO₂.kg⁻¹.jam⁻¹ and 5.90 mlCO₂.kg⁻¹.jam⁻¹, while at 15°C the rate is 6.45 mlO₂.kg⁻¹.jam⁻¹ and 20.83 mlCO₂.kg⁻¹.jam⁻¹, while at 25°C the rate is 22.33 mlO₂.kg⁻¹.jam⁻¹ and 67.91 mlCO₂.kg⁻¹.jam⁻¹. The best storage temperature recomendation with distribution time more than 30 days at 12-13°C.

Acknowledgements
This research funded by Universitas Gadjah Mada and supported by PT. Great Giant Pineapple, Lampung, Indonesia.

References
[1] Mulderij R 2018 AN OVERVIEW GLOBAL PINEAPPLE MARKET
[2] Tarigan H ., Yulius M ., Ngaro Y ., Dewi E . and Appriyadi T . 2014 Panduan Pascapanen Nenas (Jakarta: Agricultural Ministry of Indonesia)
[3] Barus A P Y 2011 Penurunan Mutu Buah Nanas (Ananas comosus (L.) Merr) Dalam Kemasan Setelah Transportasi Darat (Institut Pertanian Bogor)
[4] Rafael E 2018 Ini dia eksportir nanas 40 kontainer per hari
[5] Anwar R S 2005 Dampak Kemasan dan Suhu Penyimpanan terhadap Perubahan Sifat Fisik dan Masa Simpan Brokoli Setelah Transportasi (Institut Pertanian Bogor)
[6] Lobo M G and Paull R E 2017 Handbook of Pineapple Technology: Production, Postharvest Science, Processing and Nutrition (Chichester, UK: John Wiley & Sons)
[7] Gardjito M and Saifudin U 2011 Penanganan Pascapanen Buah-Buahan Tropis (Yogyakarta: Kanisius)
[8] Hong S I and Kim D M 2001 Influence of oxygen concentration and temperature on respiratory characteristics of fresh-cut green onion Int. J. Food Sci. Technol. 36 283–9
[9] Lee D S, Lee K S, Park I S and Yam K L 1994 Analysis of respiration characteristics of low CO2 tolerance produced for designing modified atmosphere package Foods Biotechnol. (Korea Republic) 3 99–103
[10] Yam K L, Haggar P E and Lee D S 1993 Modeling respiration of low CO2 tolerance produce using a closed system experiment Food Sci. Biotechnol. 2 22–5
[11] Benítez S, Chiumenti M, Sepulcre F, Achaerandio I and Pujolá M 2012 Modeling the effect of storage temperature on the respiration rate and texture of fresh cut pineapple J. Food Eng. 113 527–33
[12] Fonseca S C, Oliveira F A R and Brecht J K 2002 Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: a review J. Food Eng. 52 99–119
[13] Mannapperuma J D and Singh R P 1994 Modeling of gas exchange in polymeric packages of fresh fruits and vegetables ed F A R O R. P. Singh (New York, USA: Elsevier)
[14] Cameron A C, Talasila P C and Joles D W 2019 Predicting Film Permeability Needs for Modified-atmosphere Packaging of Lightly Processed Fruits and Vegetables HortScience 30 25–34
[15] Bhande S D, Ravindra M R and Goswami T K 2008 Respiration rate of banana fruit under aerobic conditions at different storage temperatures J. Food Eng. 87 116–23
[16] Caleb O, Herppich W, Mahajan P V and Atb E 2016 he Basics of Respiration for Horticultural Products Ref. Modul. Food Sci. Elsevier 1–7
[17] Hagger P E, Lee D S and Yam K L 1992 Application of an enzyme kinetics based respiration model to closed system experiments for fresh produce J. Food Process Eng. 15 143–57
[18] Lee J J and Lee D S 1996 A dynamic test for kinetic model of fresh produce respiration in
modified atmosphere and its application to packaging of prepared vegetables Food Biotechnol. (Korea Republic) 5 343–8
[19] Mangaraj S and Goswami T K 2011 Measurement and modeling of respiration rate of Guava (cv. Baruipur) for modified atmosphere packaging Int. J. Food Prop. 14 609–28
[20] Song Y, Kim H K and Yam K L 1992 Respiration rate of blueberry in modified atmosphere at various temperatures J. Am. Soc. Hortic. Sci. 117 925–9
[21] Mc Laughlin, C. P. and O’Beirne, D. 1999 Respiration {Rate} of a {Dry} {Coleslaw} {Mix} as {Affected} by {Storage} {Temperature} and {Respiratory} {Gas} {Concentrations} J. Food Sci. 64 116–9
[22] Elhadi M Yahia 2008 Modified and controlled atmospheres for tropical fruits Stewart Postharvest Rev. 2 1–10
[23] HENIG Y S and GILBERT S G 1975 Computer Analysis of the Variables Affecting Respiration and Quality of Produce Packaged in Polymeric Films J. Food Sci. 40 1033–5
[24] R.M. B, A.C. C, A. S and D.L. D L 1992 Modified-atmosphere packaging of blueberry fruit: effect of temperature on package O2 and CO2 J. Am. Soc. Hortic. Sci. 117 436–41