Modelling Respiration Rate of Chili for Development of Modified Atmosphere Packaging

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Abstract. A Michaelis-Menten equation was proposed for predicting the respiration rate of chili as a function of O₂ concentration at 15°C. The respiration rate as O₂ consumption and CO₂ production were measured using the flow-through system method. The low oxygen limit of chili was also determined by the respiratory quotient. Chili was stored at 15°C at various O₂ concentration. Using of Michaelis-Menten type respiration model provided an excellent prediction to examine the behavior of the respiration rate of chili at any O₂ concentration. The lower O₂ limit obtained in this study could be used to estimate the optimum condition in Modified Atmosphere Packaging (MAP) of chili.

Keywords: chili, respiration rate, respiratory quotient, low oxygen limit

1. Introduction

MAP is one of the quality preservation techniques by packing and sealing fresh produces in the permeable plastic film bag. The principle of this technology is also based on the establishment of low O₂ and high CO₂ atmospheric conditions around the fresh produce. The effect of MAP on quality may be related to the impact of low O₂ and high CO₂ concentration that created inside the package. It has been reported that low O₂ in MAP reduced respiration rate, ethylene production, and metabolic processes such as chlorophyll degradation, cell wall degradation, and phenolic oxidation [1]. However, when exposed under low O₂ threshold concentration, anaerobic respiration would occur, resulting in off-flavors and degradation of the tissue. Therefore, knowing the limit of low O₂ is very important for successful MAP designing.

Composition gas inside MAP depends on the balance between the respiration rate of product and gas permeation rate through the plastic film used as packaging material. If the gas permeability of film is higher than the product’s respiration rate, O₂ concentration in the package does not change, and the package does not give preservation on the quality of product. While, if the gas permeability of film is smaller than the respiration of product, O₂ concentration in the package becomes too low, where anaerobic respiration (fermentation) occurs. To maintain the quality of the product, the gas permeability of the film matches the product’s respiration, an adequate low O₂, and a high CO₂ environment are created inside the package. Therefore, knowing the respiration rate of products is fundamental in MAP designing.
Moreover, the principles of enzyme kinetics might be appropriate for modeling the respiration rate of fresh produce, and the Michaelis-Menten type equation was applied for it [2], which this equation predicted the respiration as a function of O\textsubscript{2} and CO\textsubscript{2}. It has been reported that the Michaelis-Menten type equation was successfully for modeling respiration in blueberry [3; 4], and broccoli [2].

In the previous study, we succeeded developing the mathematical model to predict the respiration rate of cucumber fruit [5] and ‘Fuyu’ persimmon fruit [6] by using the Michaelis-Menten type equation. These respiration models have been used to design the optimal MAP for alleviating chilling injury in cucumber fruit and for long-term storage of ‘Fuyu’ persimmon, respectively. As for chili, it is a perishable commodity and easy damage, mostly during storage and transportation. Stored under low temperature increases the susceptible to decay because of chilling sensitive products. Unfortunately, the lack of information on the respiration rate of chili as a function of O\textsubscript{2} concentration is limited in MAP designing. Thus, the objective of the study was to design the respiration model of chili-based on Michaelis-Menten type equation as a function of O\textsubscript{2}, and the limit of low O\textsubscript{2} of chili for development optimal MAP was also determined. In this study, the respiration rate of chili at various O\textsubscript{2} concentration was measured and modeled by using the Michaelis-Menten type equation under 15°C, which this temperature is the ideal temperature for storage chilling sensitive product [7].

2. Methods

2.1 Sample preparation

Chili (Cupscicum annum L.) was purchased from a wholesale store in Padang city, Indonesia. All fruit was sorted and selected for uniform size and absence of visual defects before the beginning of the experiment.

2.2 Respiration measurement

The sample was weighed (about 250 g) and placed into an acrylic chamber with a gas inlet and outlet. Gas compositions from 2% to 20% of O\textsubscript{2} were entered into the chamber produced from the standard gas bottles. The respiration chamber was placed in an incubator (Memmert, Germany) set the temperature at 15°C. The gas flow rate through the chamber was monitored by a flow meter and set at 100 ml min\textsuperscript{-1}. Outlet gas composition were measured by a zirconia O\textsubscript{2} sensor (MC-86, Ijima Electronic, Japan) and a solid-state CO\textsubscript{2} probe (GMP221, Vaisala, Finland). The rate of O\textsubscript{2} consumption and CO\textsubscript{2} production were calculated from the absolutes differences in gas concentration between the inlet and outlet, as mentioned by Fahmy and Nakano [5]:

\[ R_{O_2,CO_2} = \left( \frac{y_{O_2,CO_2}^{in} - y_{O_2,CO_2}^{out}}{100} \right) \times \frac{F}{W} \]  \hspace{1cm} (1)

where $R_{O_2,CO_2}$ is the respiration rate for O\textsubscript{2} consumption and CO\textsubscript{2} production of the product (mol kg\textsuperscript{-1} h\textsuperscript{-1}), $y_{O_2,CO_2}^{in}$ and $y_{O_2,CO_2}^{out}$ are volumetric concentration of O\textsubscript{2} and CO\textsubscript{2} in location h (h = inlet (in), outlet (out)), respectively (%), $W$ is the weight of the product (kg), and $F$ is flow rate (mL h\textsuperscript{-1}).

2.3 Respiration modelling

A Michaelis–Menten equation was proposed for the respiration model as a function of O\textsubscript{2} concentration following the equation as mentioned by Fahmy and Nakano [5].

\[ R_{O_2,CO_2} = \frac{V_{max,CO_2} \times [O_2]}{K_{mO_2,CO_2} + [O_2]} \]  \hspace{1cm} (2)

where $R_{O_2,CO_2}$ is the respiration rate for O\textsubscript{2} consumption and CO\textsubscript{2} production by the product (mol kg\textsuperscript{-1} h\textsuperscript{-1}), $[O_2]$ is oxygen concentration (%), $K_{mO_2,CO_2}$ is the apparent Michaelis–Menten constant (% O\textsubscript{2}), and $V_{max,CO_2}$ is the maximum respiration rate (mol kg\textsuperscript{-1} h\textsuperscript{-1}). The model parameters of the Michaelis–Menten equation were estimated by linearization of Eq. (2) as in Eq. (3).
To assure a more even distribution of error, Eq. (3) were multiplied by O\textsubscript{2} concentration as in Eq. (4). The respiration rate at O\textsubscript{2} concentration in Eq. (4) were transformed to \( \frac{[O_2]}{R_2} \) \( \frac{R_2}{CO_2} \) and then plotted against \([O_2]\). The least-squares method was used to estimate the values of \( V_{maxO_2,CO_2} \) and \( K_{mO_2,CO_2} \):

\[
\frac{1}{R_{2,CO_2}} = \frac{K_{mO_2,CO_2}}{V_{maxO_2,CO_2}[O_2]} + \frac{1}{V_{maxO_2,CO_2}} \tag{3}
\]

\[
\frac{R_{2,CO_2}}{K_{mO_2,CO_2}} = \frac{[O_2]}{V_{maxO_2,CO_2}} + \frac{[O_2]}{V_{maxO_2,CO_2}} \tag{4}
\]

2.4 Low oxygen limit

About 250 g sample was placed in an acrylic chamber with gas inlet and outlet. The chamber was placed in an incubator (Memmert, Germany) set the temperature at 15°C. The concentration of O\textsubscript{2} and CO\textsubscript{2} in the chamber was determined by a zirconia O\textsubscript{2} sensor (MC-86, Ijima Electronic, Japan) and a solid-state CO\textsubscript{2} probe (GMP221, Vaisala, Finland) until the concentration of O\textsubscript{2} in chamber achieved ±0.2%. Low oxygen limit was determined from the ratio of CO\textsubscript{2} production to O\textsubscript{2} consumption that calculated using a closed system method of respiration equation, as mentioned by Fahmy and Nakano [5].

3. Results and Discussion

Figure 1 shows the linear regression to estimate Michaelis-Menten parameters (\( V_{maxO_2,CO_2} \) and \( K_{mO_2,CO_2} \)) for predicting respiration rate of chili at 15°C under various O\textsubscript{2} concentration. These regressions were made according Eq. (4). Coefficient determination (R\textsuperscript{2}) obtained from both of regression were 0.971 and 0.990 for O\textsubscript{2} consumption rate and CO\textsubscript{2} production rate, respectively. It means that the O\textsubscript{2} concentration simultaneously affected the respiration rate of chili, and the correlation explains the strength of the relationship between an O\textsubscript{2} concentration and respiration rate.

The estimated model parameters of \( V_{maxO_2,CO_2} \) and \( K_{mO_2,CO_2} \) and of RMSE are presented in Table 1. Based on the RMSE values, the respiration model could accurately predict the respiration rate of chili under various O\textsubscript{2} concentrations at 15°C.

| Model parameter | \( R_{O_2} \) | \( R_{CO_2} \) |
|-----------------|---------------|---------------|
| \( V_{max} \) (mol kg\textsuperscript{-1} h\textsuperscript{-1}) | 0.032 | 0.008 |
| \( K_m \) (% O\textsubscript{2}) | 13.576 | 2.461 |
| RMSE (mol kg\textsuperscript{-1} h\textsuperscript{-1}) | 0.001 | 0.0004 |
Figure 2 shows the measured and predicted respiration rates of chili under various O₂ concentrations at 15°C. The predicted value was calculated from the Michaelis–Menten equation based on the principles of enzyme kinetics. The respiration rate as O₂ consumption and CO₂ production decreased in response to decreasing O₂ concentration. There was a little effect of O₂ concentration in suppressing the respiration rate from 20% to 10% of O₂, but a rapid decline in the respiration rate from 10% to 1% of O₂ was observed. These results suggest that to preserve the quality of chili at 15°C, MAP should be designed so that the O₂ concentration in the package equilibrates below 10%.

**Figure 2** Measured and predicted respiration rates of chili at various O₂ concentrations stored at 15°C. Symbols represent measured values. Solid and dotted lines indicate predicted values according to Eq. (1).

Figure 3 shows the relationship between O₂ concentration and RQ of chili at 15°C. The RQ values ranged from 0.7 to 1.2 under the O₂ concentration from 11.7% to 2.99%, with an average value of 1.0. This value corresponds with RQ measured by a closed system method shown in cucumber fruit ranged from 0.6 to 1.2 [5]. Kader [8] also reported that the normal RQ value is ranging from 0.7 to 1.3. When the O₂ concentration fell below 2.99, the RQ value increased abruptly, and thus this O₂ level could be defined as the critical low O₂ limit of chili at 15°C. The obtained low O₂ limit in this study was very close with the recommendation of O₂ concentration for chili, given as 3% to 5% [7].

**Figure 3** plotted the relationship between O₂ concentration and Respiratory Quotient (RQ). The symbols represent measured values.
4. Conclusion

In this study, we developed the mathematical model to predict the respiration rate of chili at 15°C as a function of O₂ concentration using the Michaelis-Menten equation. Model parameters obtained in this predicted respiration rate chili accurately. On the other hand, the low oxygen limit was also obtained and could be used to develop optimal condition inside MAP.

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