Prediction of Respiration Measurement Based on Temperature Differences of Fresh Strawberry (*Fragaria* x *ananassa* var. Kelly Bright) in a Tropical Environment

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ABSTRACT

Strawberry is a high-economic-value horticultural product that can be cultivated in tropical areas like Indonesia. Horticultural products retain their metabolism after harvest, such as respiration, which is an indicator of the degradation of products during storage. This study aimed to determine the best equation for predicting the respiration of strawberries cultivated using hydroponics in a greenhouse in Cangkringan, Yogyakarta. The respiration rate during storage was measured using an oxygen meter (DO-5510, Lutron, Taiwan) and a carbon dioxide meter (GH-2018 model, Lutron, Taiwan) in a closed system using an acrylic closed chamber. Five types of Michaelis-Menten equations were chosen as the best type based on R^2. The Arrhenius equation was used to get the highest value of R^2 to predict the effects of temperature on respiration. Statistical analysis was used to determine the impact of treatments on the respiration rate. Based on the Arrhenius equation, the respiration of strawberries on postharvest in tropical environments depended on temperature. The best type for predicting the respiration of strawberries using the Michaelis-Menten mathematical model is competitive with an R^2 value of 0.88. Therefore, the appropriate postharvest treatment is essential to add carbon dioxide or reduce oxygen levels.

Keywords: Arrhenius; Fresh-Strawberry; Michaelis-Menten; Respiration; Tropical-Environment

INTRODUCTION

Strawberry (*Fragaria x Ananassa* var. Kelly Bright) is a horticultural product that still produces metabolic reactions after being harvested. Strawberries are one of the Mediterranean plants (Gardjito et al., 2015), but they can also grow in tropical environments such as Indonesia (Budiman & Saraswati, 2008). According to Choopong & Verheij (1997), cultivating strawberry plants in the tropics could be successful in highland areas with elevations above 1000 m above sea level (asl) with temperatures of 17-20ºC. However, the research conducted by Rizky (2019) showed that strawberries could grow well in Argomulyo, Cangkringan, Sleman Regency, Yogyakarta, which has a temperature of 23-30ºC. Strawberries in the study were cultivated in a hydroponic greenhouse.

The metabolic activity of strawberries after experiencing the harvesting process can cause damage (Falah et al., 2016; Garavito et al., 2021), which is generally related to respiration (Keshri et al., 2020). In general, the process of respiration in a product is the breakdown of polysaccharides into simple sugars, oxidation of sugar into pyruvic acid, and transformation of pyruvate and other organic acids into carbon dioxide, water, and energy that takes place (Rahmadhanni et al., 2020).

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The respiration rate is determined by measuring the amount of carbon dioxide gas, water vapor, and energy produced. Respiration rate measurement can use several methods, including closed, gas flow, and permeable systems. The most frequently used in agricultural product research is a closed system because it is a suitable measurement method for measuring the respiration rate of fresh products (Alhamdan et al., 2015; Keshri et al., 2019, Ono et al., 2022).

According to Fonseca et al. (2002) and Sousa et al. (2017), the respiration rate and mathematical model of the respiration equation from the products subjected to modified atmospheric storage methods are crucial things that determine the method's success. Hence, respiration rate data and product respiration models are necessary to support the success of the modified atmospheric storage method. Sari (2015) argues that the higher the respiration rate, the faster the damage to the product. Therefore, the respiration rate is one indicator that indicates the metabolic rate in agricultural commodities (Yassin et al., 2013) to determine quality degradation, including strawberries, and the basis for making modified atmosphere storage/packaging. Respiration is the primary process of degradation of fresh products. It can be considered a metabolic process aimed at the oxidative breakdown of organic substrates into simpler molecules than those before oxidative breakdown (Fonseca et al., 2002). Lee et al. (1996) proposed a respiration model based on enzyme kinetics to predict the respiration rates of fresh products as a function of oxygen and carbon dioxide concentrations. Enzyme kinetics principles might be suitable for modeling the respiration rate of fresh products (Yang & Chinnan, 1988). Fagundes et al. (2013) and Yang & Chinnan (1988) propose that a Michaelis-Menten-type equation model can be used, considering that respiration in fresh produce is possibly commanded by an enzymatic reaction catalyzed by enzymes and regulated through inhibition. High carbon dioxide concentrations can reduce the oxygen consumption rate of several fruits and vegetables. Three types of inhibition can model this reduction in an enzyme kinetics model. The types are competitive, uncompetitive, and non-competitive.

On the other hand, temperature is an external factor that can affect the respiration rate, maintain quality, and extend the shelf life of agricultural products (Falah et al., 2016). According to Sari (2015), the increase in temperature that occurs can have an impact on increasing product respiration rates. The effect of temperature can be seen using the Arrhenius equation. The Arrhenius equation states the relationship between activation energy and reaction rate of respiration rates. A chemical reaction can occur if there are collisions between the molecules inside. Chemical reactions can be accelerated by reducing the activation value of energy.

On the contrary, a chemical reaction can be slowed down by increasing the activation value of energy. Activation energy can be enlarged by lowering the reaction temperature and reduced by increasing the reaction temperature. Hence, the lower the reaction temperature, the slower the reaction rate. This principle can be applied to agricultural technology. Extending the shelf life of agricultural products can be done through storage at low temperatures, considering the possibility of chilling injury in the fresh products. Based on it, the respiration rate and mathematical modeling with different storage temperatures in the tropical environment must be studied. **Therefore, this study aimed to determine** the best type of equation for predicting the respiration of strawberries using three different temperature models and the effect of temperature using the Arrhenius approach during storage.

MATERIALS AND METHODS

The strawberry plants were cultivated inside the greenhouse with dimensions of LxWxH = 922x402x410 cm, which can be seen in Figure 1, in Jetis, Argomulyo, Cangkringan, Sleman, with an average air temperature of 26–41.6ºC and air humidity of 62.26–85.32%. The strawberry plants were cultivated using conventional soil as a control (C) and hydroponic with nutrient film technique (NFT). The flow of nutrients was continuous and accommodated in the reservoir—both cultivations used a nutrient concentration of 4mS/cm (salt-stress condition) with 192 plants. The nutrients consisted of 15.40% Carbon, 61.34 mg/L of Phosphorus, 155.07 mg/L of Sulphur, 231.85 mg/L of Potassium, 236.50 mg/L of Magnesium, and 0.15% NaCl.

This study, basically based on the Rizky et al. (2019), was arranged in a completely randomized design with variations in three different post-harvest storage temperatures for strawberries, including the optimal temperature of 4 ± 2ºC (OT), storefront/market temperature of 15 ± 2º C (ST), and the room temperature as a control of 27 ± 2ºC (CT), with five replications. A measured and calculated respiration rate using an acrylic closed chamber is illustrated in Figure 2. Upon completion, oxygen and carbon dioxide levels were measured with oxygen concentration using an oxygen meter (DO-

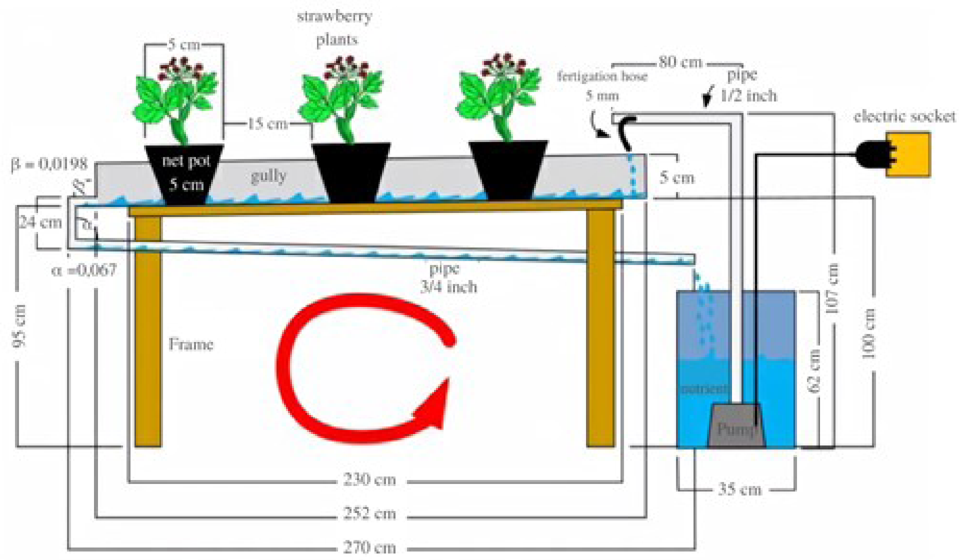

Figure 1. Hydroponic cultivation of strawberries using NFT system planting design

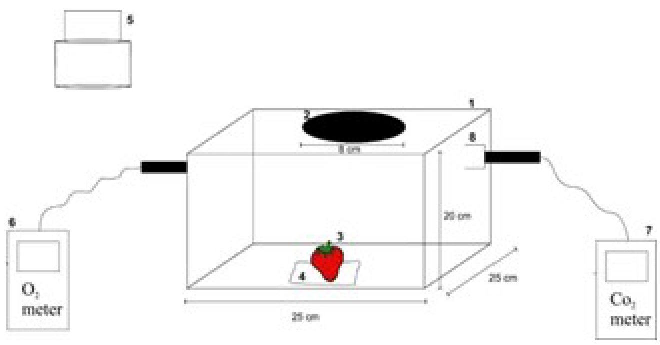

Figure 2. Close chamber system from acrylic for measuring respiration rate with the sensor of oxygen and carbon dioxide

5510, Lutron, Taiwan) and carbon dioxide meter (GH-2018 model, Lutron, Taiwan) for 24 hours with the interval data of 2 hours with 15 minutes of data collection intervals. Different measurements were made on the first day because strawberries are fruits with high respiration rates (Phan et al., 1975). The respiration rate on the first day of strawberries will be higher than the next storage day.

Measurement of Oxygen and Carbon Dioxide Respiration Rate

The calculation used to obtain the value of respiration is a calculation that refers to the research of Ravindra & Goswami (2008) with the following formula:

$$RO_2 = \frac{dGO2}{dt}\frac{dGO_2}{dt} \times \frac{Vfr}{w}\frac{Vfr}{w} \qquad (1)$$

$$RCO_2 = \frac{dGCO2}{dt}\frac{dGCO_2}{dt} \times \frac{Vfr}{w}\frac{Vfr}{w} \qquad (2)$$

$$\frac{dGO2}{dt}\frac{dGO_2}{dt} = \frac{GO2\ at\ (t) - GO2\ pada\ (t+1)}{Dt}\frac{GO_2\ at\ (t) - GO_2\ at\ (t+1)}{Dt} \qquad (3)$$

$$\frac{dGCO2}{dt}\frac{dGCO_2}{dt} = \frac{GCO2\ at\ (t) - GCO2\ at\ (t+1)}{Dt}\frac{GCO_2\ at\ (t) - GCO_2\ at\ (t+1)}{Dt} \qquad (4)$$

Remarks:

RO_2 = O_2 respiration rate (ml O_2/kg.h)

RCO_2 = CO_2 respiration rate (ml CO_2 / kg. Hour)

Vfr = free volume (mL)

Vfr = V jar - V product

Vproduct = (m total)/ρ

W = product weight (kg)

$(dGO_2)/dt$ = the ratio between the difference in O_2 concentration at a certain time interval divided by the time difference

$(dGCO_2)/dt$ = the ratio between the difference in CO_2 concentration at a certain time interval divided by the time difference.

Michaelis-Menten Modeling

The Michaelis-Menten equation is a satisfactory description of enzyme kinetics in industries, and this equation's similarity explains the relationship between substrate concentration and reaction rate (Arda, 2010; Marni et al., 2020; Ho et al., 2020). There are five types of Michaelis-Menten's equation (Peppelenbos & Van, 1996; Sari, 2015; Rahayu et al., 2021), including 1) competitive; model type of competitive inhibition occurs when inhibitors (CO_2) and substrate (O_2) compete to fill the active part of the enzyme, 2) uncompetitive inhibition; this type occurs when the inhibitor (CO_2) reacts with a complex enzyme substrate; therefore, the high concentration of CO_2 has little effect on the respiration rate, 3) non-competitive inhibition, which occurs when the inhibitor (CO_2) works by attaching itself to the active side of the enzyme; thus, the enzyme's shape changes, and the operational side no longer functions, causing the substrate not to enter the enzyme's playful side; 4) combination inhibition; this type occurs when inhibitors (CO_2) and substrate (O_2) compete to fill the active part of the enzyme and when the inhibitor (CO_2) reacts with a complex enzyme-substrate, 5) without inhibition; this model shows the respiration rate where carbon dioxide does not affect the reaction. Substrate (oxygen) reacts with enzymes that produce complex substrate enzymes without any influence from carbon dioxide.

Arrhenius Equation

The Arrhenius equation is commonly used to express the dependence of the reaction rate constant on temperature. The effect of temperature can be seen using the Arrhenius equation; it is the most commonly and very accurately used equation to describe the impact of temperature on chemical reaction rates (Kohout, 2021; Lugt, 2022). The Arrhenius equation states the relationship between activation energy and reaction rate (Gutiérrez et al., 2019), which can be used to determine the effects of temperature. The equation is as follows:

$$k = Ae^{(-Ea / R * T)} \quad (5)$$

This equation states the relationship between activation energy (Ea) and the impact frequency that occurs (A), in which R is the gas constant (8.314 J/K.mol), T is the absolute temperature, and e is the basis of the natural logarithmic scale. Ea and A values are obtained from the average value of respiration rate (k) that has been received. Then, the value of k is entered and plotted with 1/T (K). So the equation results in Y = ax + ab, where y = ln k, x = 1 / T, a = -Ea / R, and b = ln. After the graph, the Ea and A values are obtained by multiplying the value of -a and R, and A is obtained using the value of b. The lower the Ea value, the faster the reaction occurs and vice versa (Rahayu et al., 2021)

RESULTS AND DISCUSSION

Characteristics of Strawberry Fruit Samples

The ready-to-harvest strawberries used as the research samples are fruits with a maturity level of 2/3, characterized by relatively hard fruit texture and fruit's skin dominated by red, reddish green, until yellow and reddish but still white, and orange with the nutrient content of strawberry listed in table 1.

Table 1. Nutrient content of strawberry cultivated under EC of 4 mS/cm

Variables	Result	Unit
C (Carbon)	15.40	%
P (Phospor)	61.34	mg/L
S (Sulfur)	155.07	mg/L
K (Potassium)	231.85	mg/L
Mg(magnesium)	236.50	mg/L
NaCl	0.15	%

Source: Afrianti (2017)

The fruit with full maturity is two weeks from flowering or about ten days after the formation of the fruit (Rukmana, 1998). Hence, the maturity 2/3 is approximately eight days old (Falah et al., 201) (Figure 3).

Figure 3. Strawberry with 2/3 maturity

Harvesting was done by picking or cutting the fruit stalks and petals. Strawberry fruits were immediately taken to the laboratory for storage. Strawberry crop cultivation implemented a conventional soil control system (C). The treatment of strawberry cultivation compared with the control using products from NFT cultivation is presented in Figure 1.

Oxygen Level and Respiration Rate During Respiration Storage

The process of respiration results from the breakdown of oxygen into simple compounds. This causes a decrease in oxygen levels. The results from measuring oxygen levels during storage are shown in Figure 3, based on the measurement and calculation using equations 1-4 and Figure 2.

Figure 4A shows a decrease in oxygen levels during storage. The most significant reduction in oxygen levels at the beginning of storage is the change in oxygen from zero-day to the first day of storage. According to Santoso (1995), in non-climacteric fruits such as strawberries, the respiration rate will rapidly decrease until decay finally occurs. Several factors can affect the rate of respiration, one of which is the temperature and morphology of the fruit. High temperatures can speed up the consumption of O_2, and vice versa. At low temperatures, the rate of decline in O_2 levels runs slowly.

Figure 4A shows that strawberries stored at room temperature have decreased oxygen levels faster than those stored at low temperatures. According to Sari (2015), storage at low temperatures can reduce respiration rate, but too low temperatures can also lead to chilling injury damage. Falah et al. (2018) state that the optimal strawberry storage temperature is 4°C.

The fruit quality will last longer if the low respiration rate and transpiration can be prevented by keeping the storage temperature of the fruit low (Tranggono & Suhardi, 1990). Based on Figure 4B, the respiration rate occurs slowly at a storage temperature of 4±2°C. The initial level of O_2 was around 20.9-21.1%, decreased to 13-14.5% at room temperature of 27±2°C. At temperatures of 15±2°C, the O_2 level decreased to 10-11%; at temperatures of 4±2°C, the O_2 level decreased to 3.5-5%.

Decreasing oxygen levels runs slowly at low storage temperatures because fruit metabolism is slow at low temperatures, and the water content from commodities is also tiny. It can be interpreted that low temperatures can control transpiration. Santoso (1995) states that for every 10°C increase in temperature, the respiration rate will increase by two to two and a half. With rising respiration rates, oxygen consumption will also be high.

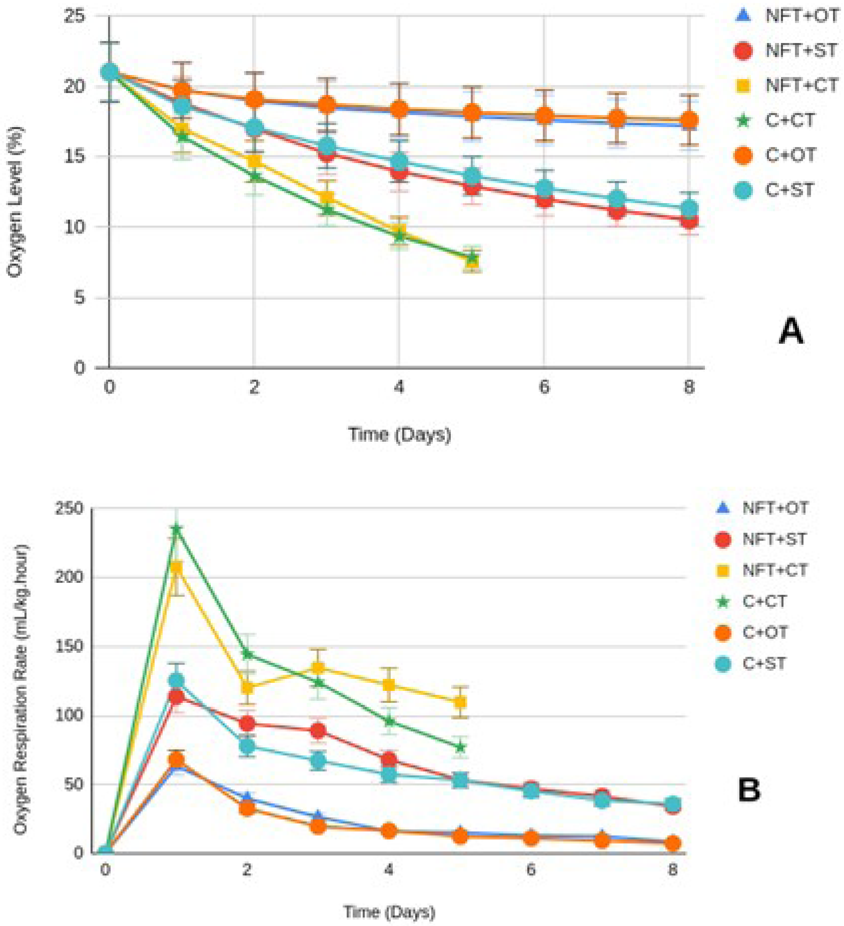

Figure 4. Change in O_2 level (A) and respiration rate (B) during measurement under three different storage temperatures using NFT and soil cultivation. The data shown were averaged from five replications with a standard deviation for each measurement.

Low storage temperature also has a disadvantage, in which commodities can be damaged if the temperature is not optimal. Therefore, to prevent damage, commodities are stored at optimal temperatures. The optimal storage temperature varies for each commodity. In strawberries, the optimal temperature Falah et al. (2018) recommended is 4ºC. Like the morphology of the fruit, the surface area and surface coating of fruit material (cuticle thickness, stomata, and lenticel) also affect oxygen consumption because this is related to gas diffusion. More stomata and lenticels indicate a less dense fruit structure, speeding up the gas diffusion process and increasing oxygen consumption. In addition, the climatic conditions and ways of cultivating strawberries affect the physical and chemical quality. The fruit structure in NFT strawberries is not dense and contains much water, which causes oxygen consumption to run faster in NFT strawberries than in soil-cultivated strawberries.

The result of calculating the respiration rate can be seen in Figure 4B. Oxygen level data (Figure 4A) were processed using mathematical equations, resulting in the respiration rate value (RO_2). Based on the graph in Figure 4B, the respiration rate was high on the first day of storage and then decreased until it reached a constant value during the next storage day. However, the respiration rate was slower at low storage temperatures than at room temperature. The respiration rate in strawberry samples with a storage temperature of 4±2ºC was lower than that of 15±2ºC and room temperature (27±2ºC). The respiration rate constantly started on the seventh and eighth days of storage. Therefore, the observation was stopped on the eighth day because it is assumed that the respiration rate will remain constant. Although the respiration rate has not reached 5%, strawberries have been categorized as rotten/damaged physically. This is because the respiration rate is not the only indicator of fruit damage (Błaszczyk et al., 2022).

Strawberry fruits originating from NFT showed a faster oxygen respiration rate than soil-cultivated strawberries because the fruit structure was less dense and more dominated by water than ingredients such as organic acids needed for respiration (Falah et al., 2020). Thus, the respiration rate became faster due to the limited availability of the ingredients needed for respiration. The solid structure of the strawberries also affects the thickness of the cuticle, stomata, and lenticel. It is associated with gas diffusion. The denser the structure of the strawberry, the faster the respiration rate (Paul & Pandey, 2014; Gardjito et al., 2015).

The effect of treatment on oxygen respiration rate was statistically analyzed using SPSS. The statistical analysis was two-way ANOVA and Duncan Multiple Range Test (DMRT). From the results of the statistical tests, it can be seen that temperature significantly affects oxygen respiration rate. In contrast, the planting media and the interaction between the growing media and temperature do not have a significant effect (Barrios et al., 2014; Dziedzic et al., 2020).

According to Gardjito et al. (2015) and Xanthopoulos et al. (2017), respiration rates are also influenced by commodity types and genotypes, stages of commodity development at harvest, and chemical composition. The surface area of the fruit surface also influences the respiration rate because they are related to gas diffusion. Climate and weather conditions of farming indirectly can affect the morphological properties and composition of an agricultural material, ultimately affecting the respiration rate.

Carbon Dioxide Level and Respiration Rate During Storage

The respiration process produces simple compounds such as CO_2 and H_2O so that generally, CO_2 levels will increase. The change in CO_2 level and respiration rate during storage is presented in Figure 5.

Based on the graph of Figure 5A, there is an increase in changes in carbon dioxide levels. The most significant increase in carbon dioxide levels occurs on the zero-day towards the first day. From the graph in Figure 5A, the carbon dioxide levels of the strawberries stored at optimal storage temperature (OT) and showcase temperature (ST) started to be constant on the seventh and eighth day of storage. Therefore, the observation was stopped on the eighth day. Carbon dioxide levels generally increased faster in samples stored at room temperature. Significant changes in carbon dioxide levels occurred due to the high temperature of the storage room.

In strawberries cultivated with NFT, the increase in carbon dioxide levels was faster than in the soil-cultivated strawberries. It is influenced by the morphology of the fruit, surface area, and surface coating material (cuticle thickness, stomata, and lenticel). It also affects carbon dioxide production because it is related to gas diffusion. The greater the stomata and lenticels, the more the oxygen

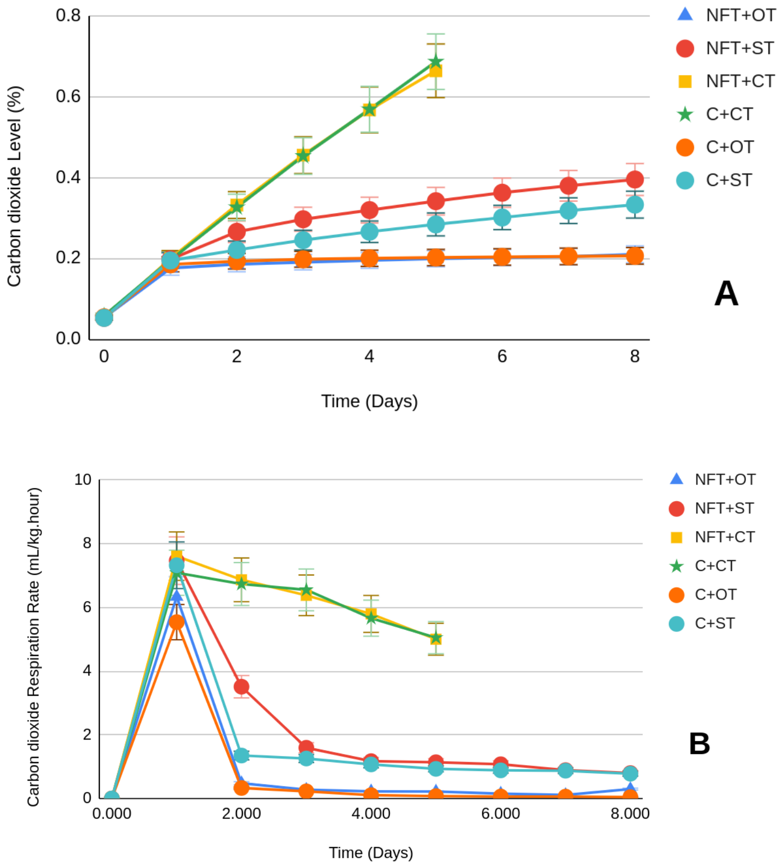

Figure 5. Change in CO_2 level (A) and respiration rate (B) during measurement under three different storage temperatures using NFT and soil cultivation. The data shown were averaged from five replications with a standard deviation for each measurement.

consumption and carbon dioxide production because the gas diffusion process also runs faster. It causes carbon dioxide production to run faster in NFT strawberries than in soil-cultivated strawberries (Paul & Pandey, 2014; Gardjito et al., 2015).

The data on carbon dioxide levels were processed using mathematical equations to obtain the respiration rate (RCO_2), which can be seen in Figure 5. The carbon dioxide respiration rate at room temperature storage showed a higher value than at optimal temperature and showcase temperature. The carbon dioxide respiration rate can be suppressed in low storage temperatures. These results follow the opinion of David & Juliana (2016), stating that good cooling and temperature management to reach the lowest point or critical point will undoubtedly significantly affect the inhibition or suppression of the respiration rate, which can ultimately inhibit the destruction process.

Besides temperature, the structure of strawberry fruit can also affect the carbon dioxide respiration rate. This is because the structure of strawberries is related to the ingredients needed for respiration and is also related to gas diffusion. In NFT strawberries, the respiration rate is faster than soil-cultivated strawberries because soil-cultivated strawberries have a denser structure than NFT strawberries. Hence, organic acids, which are needed for respiration, are more present in soil-cultivated strawberries. The more materials required for the respiration process, the slower the rate of respiration, and vice versa (Fonseca et al., 2002)

The effect of treatment on carbon dioxide respiration rates was also statistically analyzed using SPSS. The test is a two-way ANOVA. From the results of the statistical tests, it can be seen that the temperature significantly affects the carbon dioxide respiration rate. In contrast, the planting media and the interaction between the growing media and the temperature do not have a significant effect. After the ANOVA test, the Duncan Multiple Range Test (DMRT) was performed, and it can be seen that low storage temperature showed significantly different results compared to room temperature. Both strawberry samples from soil media (C) and NFT stored at low temperatures differed from strawberry samples derived from soil media (C) and NFT stored at room temperature.

Effect of Temperature on Respiration Rate

Temperature is an external factor that can affect respiration rate, maintain quality, and extend the shelf life of agricultural products. According to Sari (2015), the increase in temperature that occurs can have an impact on increasing product respiration rates. According to Mahajan et al. (2001) and Gutiérrez et al. (2019), the effect of temperature on respiration rate can be analyzed using the Arrhenius equation by looking at the regression of the relationship between temperature and respiration rate (Figure 6).

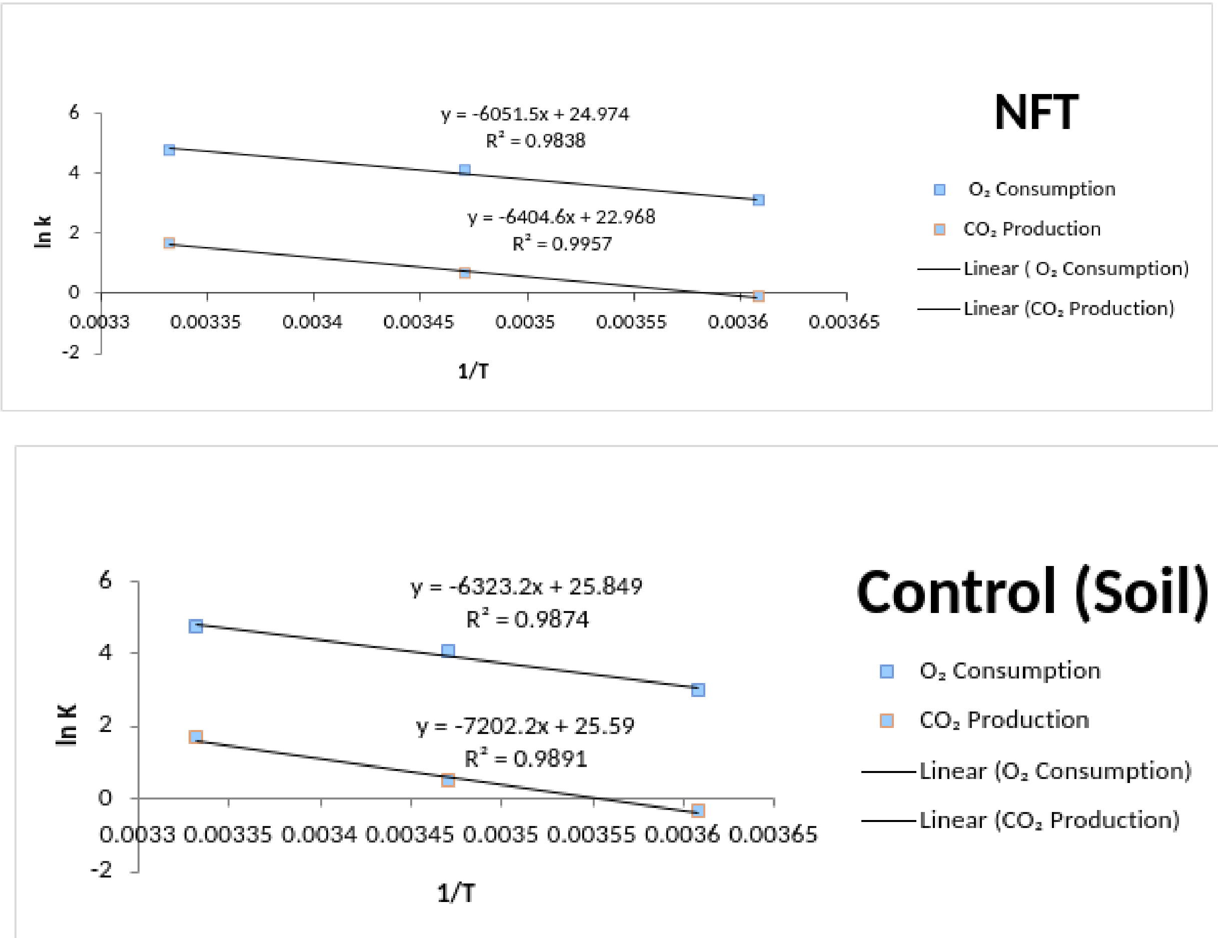

Figure 6. Linear regression graph ln k vs 1/T for respiration rate

The Ea and A values results were obtained from the calculations and presented in Table 2.

Table 2. Value of Ea and A for respiration rate in various types of strawberries

Value	Oxygen				Carbon Dioxide			
	Ea (J/mol)	A (gr/jam)	a	b	Ea (J/mol)	A (gr/jam)	a	b
NFT	50315.03	70156900048	-6051.5	24.974	53250.867	9.438E+09	-6404.6	22.968
C	52574.07	1.68298E+11	-6323.2	25.849	59882.49	1.299E+11	-7202.2	25.59

The activation energy value (Ea) obtained is still within the recommended range for fruit activation energy. The typical age for vegetables and fruits ranges from 29-93 kJ / mol (Exama et al., 1993). Sari (2015) states that energy activation occurs because of molecule collisions: the more collisions, the more significant the activation energy produced.

The highest Ea value was in the soil-cultivated strawberries, and the lowest Ea value was in the strawberries derived from NFT hydroponic cultivation. Chemical reactions will occur faster at low Ea values, so strawberries originating from NFT hydroponic cultivation have fast chemical reactions. Chemical reactions in respiration are where glucose and oxygen are broken down into carbon dioxide, water, and energy. Activation energy is sufficiently large to decrease this chemical reaction to collapse the respiration rate. Therefore, considerable activation energy is needed to slow the respiration rate (Kasim et al., 2022)

After the Ea and A values were obtained, the k value can be determined by calculating the Ea and A values following the Arrhenius equation.

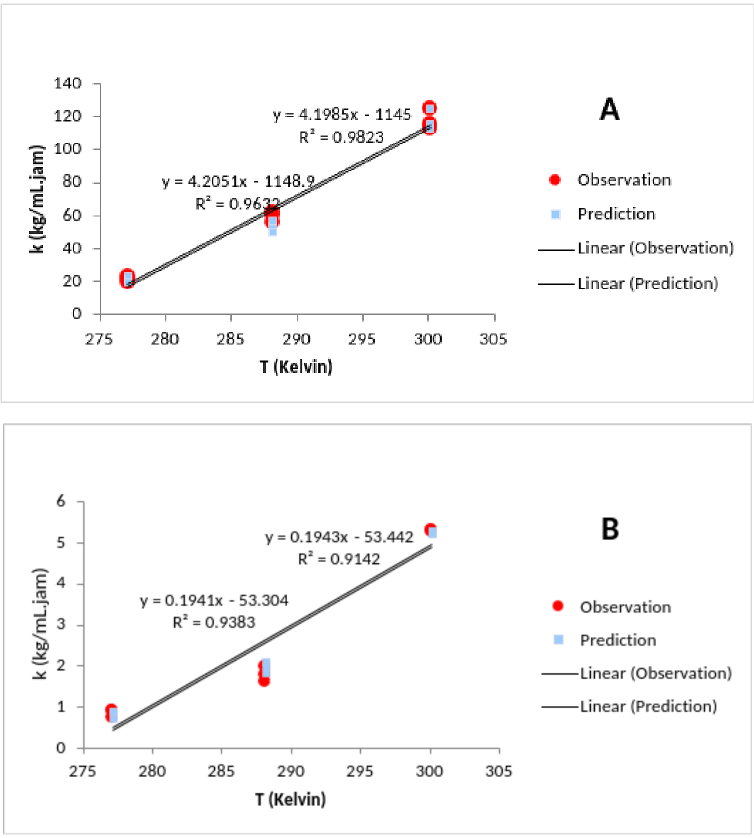

Figure 7. Linear regression graph ln k vs 1/T for respiration rate

Table 3. Arrhenius equation model

Sample	Equation Model O_2	Equation Model CO_2
NFT	$k = 70156900048 \times e^{-\frac{50315.03}{RT}}$	$k = 9.438E + 09 \times e^{-\frac{53250.867}{RT}}$
C (Soil)	$k = 1.68298E + 11 + 11 \times e^{-\frac{(52574.07)}{RT}}$	$k = 1.299E + 11 \times e^{-\frac{(59882.49)}{RT}}$

The equation model was then validated by comparing the estimated k value with the observed k value and the validity value (Figure 7). The respiration rate graph is estimated (prediction) compared to the respiration rate value from the calculation (observation). These results are used to see the accuracy of the model made. The graph of observation versus prediction shows the validation value of the model of the respiration rate equation for oxygen and carbon dioxide. The results of comparing predicted with observed values have a linearity value of one. It means that estimated data generated using the Arrhenius equation model has the same value or is close to the observation data (Sari, 2015).

Comparison of the Michaelis-Menten respiration rate model

The rate of respiration can be predicted using any of the Michaelis-Menten types. Which models, though, will be selected based on which types best capture the pattern of respiration rates. The effects of carbon dioxide on the respiration process were investigated by determining which model best captures the actual respiratory rate. The validation values for the different Michaelis-Menten types are shown in Table 4.

Table 4. The highest R^2 values of Michaelis-Menten's five types under different temperatures and cultivation in various treatments

Type R^2	Sample	Temperature			Average	Average R^2
		4±2⁰C	15±2⁰C	27±2⁰C		
Without inhibition	NFT	0.9355	0.879	0.5546	0.7897	0.854
	C	0.9188	0.9171	0.9197	0.9185	
Competitive	NFT	0.9362	0.8629	0.9695	0.9229	**0.88**
	C	0.8534	0.9515	0.7073	0.8374	
Uncompetitive	NFT	0.9733	0.784	0.635	0.7974	0.831
	C	0.8264	0.859	0.9056	0.8637	
Non-competitive	NFT	0.8954	0.8951	0.1685	0.653	0.584
	C	0.3763	0.8685	0.3025	0.5158	
Combination	NFT	0.8212	0.5724	0.6136	0.6691	0.707
	C	0.5484	0.8583	0.8309	0.7459	

The values of R^2 obtained were then selected based on the highest value. Overall, the appropriate Michaelis-Menten equation model is the competitive type. In this study, carbon dioxide acts as an inhibitor, and oxygen acts as a competitive substrate to occupy the active side of the enzyme. Therefore, the presence of carbon dioxide affects the respiration rate. The increased oxygen acting as a substrate can significantly affect the oxygen consumption rate. Meanwhile, the presence of carbon dioxide, which acts as an inhibitor, can reduce the chance of forming a substrate enzyme complex, thereby decreasing respiration rate (Fonseca et al., 2002)

In the competitive type, the appropriate post-harvest treatment to extend the shelf life of strawberries is by adding carbon dioxide levels or reducing oxygen levels. As the oxygen level decreases, carbon dioxide binds to the enzyme's active side, suppressing the respiration rate. This is due to the inhibitory effect of carbon dioxide on respiration. On the other hand, when carbon dioxide levels are increased, more carbon dioxide binds to the active side of the enzyme, which can reduce the respiration rate (Fagundes et al., 2013).

CONCLUSION

The best equation type for predicting the respiration of strawberries using Michaelis-Menten's mathematical model is competitive with an R^2 value of 0.88, in which there is competition between oxygen and carbon dioxide to fill the active part of the enzyme that plays in the respiration rate. The appropriate post-harvest treatment is important to add carbon dioxide or reduce oxygen levels. This respiration rate is highly affected by temperature, based on the Arrhenius R-value, with an R^2 value of oxygen and carbon dioxide of 0.9727 and 0.9262, respectively.

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