Kinetics of physical quality of Pineapple fruit (*Ananas comosus* L.) with crown during storage with temperature variation

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Abstract. Pineapple is the fruit that ranks the fourth largest production in Indonesia. Pineapple fruit is a non-climacteric fruit that is easily damaged, so the effort to extend the shelf life of the fruit can be done by storing it in cold temperatures. This study aims to analyze the pineapple kinetics with crowns during storage with temperature variations. The research sample was in the form of pineapple Smooth Cayenne varieties stored at low temperatures (7 and 15°C), and the control treatment was stored at room temperature (25°C). Changes in the physical quality of pineapple during storage were observed with shell color parameters, weight loss, and texture. Observations were carried out at intervals ranging from 2-3 days to 16-20 days of storage depending on storage temperature. Fruit damage rates based on measured parameters were analyzed using the Arrhenius and kinetic model approaches. The results showed changes in low temperature storage are: shell color 0.00-10.67%, weight loss 0.00-3.70%, hardness 3.955-3.062 kg.cm⁻². Control treatment: shell color 0.00-100%, weight loss 0.00-13.89%, hardness 3.898-1.982kg.cm⁻². Constant (k) kinetics at low temperature are: shell color 0.4921-5.6901%.day⁻¹, weight loss 0.1939-0.2683%.day⁻¹, hardness (-0.0679)-(0.1013)kg.cm⁻².day⁻¹. Control treatment: shell color 7.7994 %.day⁻¹, weight loss 0.7837 %.day⁻¹, hardness -0.1276 kg.cm⁻².day⁻¹. The values of A and Ea (in J.mol⁻¹.K⁻¹) Arrhenius are: shell color 1.997x10¹⁹ and -1.0427x10⁵, weight loss 2.554x10⁰ and -5.454x10⁴, hardness 2.213x10³ and -2.411x10⁴.

1. Introduction
Pineapple (*Ananas comosus* L.) is a type of fruit plant from the family Bromeliaceae [1-3]. Pineapple comes from the lowlands of America and the Caribbean [4]. In every 100 grams of pineapple, it contains 88.9% water, 40 cal energy, 22 mg vitamin C, 111 mg potassium, 22 mg calcium, and other beneficial compounds [5]. Pineapple also contains polyphenols, flavonoids, and good free radical capture capacity [6]. Pineapple is the 12th largest fruit production in the world and in 2018, Indonesia is number 9th country with largest production of pineapple with total production 1.39 million ton [7,8]. In Indonesia, pineapple sequences in 4th largest fruit production with Lampung Province as the largest contributor (35%) especially from PT Great Giant Pineapple [9].

Pineapple is a non-climacteric fruit that is easily damaged, so it needs proper handling [10]. Postharvest handling in Indonesia is not optimal and postharvest damage often occurs at 25-28% [11]. Postharvest damage that often occurs is the distribution process such as: physiological damage to fruit, physical damage due to loading and unloading, use of inadequate containers, and delay in distribution [12]. Storage temperatures that are too high will also speed up damage due to metabolic activity [13].
During the harvesting process, horticultural products still experience metabolic activity [14]. Changes in the physical quality of pineapple during ripening are characterized by changes in skin color, decreased moisture, nutrients, hardness and will be exacerbated by high storage temperature [15,16]. For this reason, cold storage is needed to maintain the quality of the fruit and extend shelf life [17]. Low temperature storage can increase pineapple shelf life 2-4 weeks, but must pay attention to the right temperature [18]. Recommendation for storing pineapple at a temperature of 7-12°C with RH 85-95% [19]. Maximum storage at 7°C lasts up to 4 weeks. Storage at temperatures less than 7°C can cause chilling injury and storage at 2-4°C browning will occur [20]. Damage due to chilling injury includes wilt, dryness, leaf discoloration on the crown, browning the skin of the fruit, and browning on fruit flesh [21]. For this reason, it needs to be investigated further regarding the influence of temperature on changes in the physical quality of pineapple fruit so that optimal storage temperatures can be known so that the fruit that arrives in the hands of consumers remains high quality.

2. Methodology

2.1. Experimental Procedures

2.1.1. Sample Preparation. The study was conducted in January-March 2019 at the Food and Postharvest Engineering Laboratory, Department of Agricultural Engineering and Biosystems, Universitas Gadjah Mada. The study was conducted using Smooth Cayenne varieties of fresh pineapple from PT. Great Giant Pineapple, Lampung, Indonesia through supermarkets in Yogyakarta after being distributed around 2 days. Pineapple is of medium-large quality (1.7-2.5 kg) or with a maturity level of 0-5%. Pineapple is cleaned from dirt then weighed and labeled. Then the pineapple is put into a cardboard box with 7 pineapple contents in each cardboard and stored in cold storage at temperatures of 7°C and 15°C and as a control it is stored at room temperature 25°C with moisture being kept as hard as 90%. Changes in physical quality parameters observed were the level of maturity, weight loss, and hardness.

2.1.2. Maturity Level. Measurement of the maturity level of pineapple using the standards of PT. Great Giant Pineapple is based on a change in the color of the eye skin (shell color) [22]. Previously, pineapple was categorized based on fruit weight as in Table 1. to determine the number of fruit peel eyes.

| Category | Weight | Amount of eyes skin |
|----------|--------|---------------------|
| Small    | ≤1,1 s/d 1,4 Kg | ≤6                   |
| Medium   | >1,4 s/d <1,8 Kg | 7-8                  |
| Big      | ≥1,8 Kg       | 9-10                 |

After that, count the number of yellow shell color in the same lane vertically from the bottom base and convert the number of mature fruit eyes to the percentage of maturity as in Table 2. [22]. The measurement of the percentage of fruit maturity is done at 2-3 days intervals to maximum maturity.

Table 2. Percentage of Pineapple Maturity Conversion

| Maturity of eye skin | Small  | Medium | Big    |
|---------------------|--------|--------|--------|
| 0                   | 0 %    | 0%     | 0%     |
| 0,5                 | 8,34 % | 6,25 – 7,15 % | 5 – 5,55 % |
| 1                   | 16,67 %| 12,5 – 14,29 % | 10 – 11,11%|
| 1,5                 | 25,01 %| 18,75 -21,44 % | 15 – 16,66 %|
2.1.3. Weight Loss. Measurement of weight loss is done by measuring the initial sample weight and final weight when collecting data during measurement. To calculate the percentage of weight loss with the equation: 2.1.

\[ WL = \frac{m_i - m_f}{m_i} \times 100\% \]  
(2.1)

Where WL is weight loss percentage (\% day\(^{-1}\)), \( m_i \) is the initial mass (g), \( m_f \) is the final mass of fruit (g).

2.1.4. Hardness. Measurement of hardness was carried out by cutting pineapple samples in the middle of the fruit flesh with a size of 3x3x1 cm (p x l x t) and then measured the hardness of fruit flesh using the Texture Analyzer LV-1000 with TA41 probe type with a diameter of 0.5 cm. The depth of stabbing is 0.5 cm. The results of the data are displayed in the form of a hardness cycle (g). The measurement data is then calculated using equation 2.2 to determine the value of fruit hardness.

\[ P = \frac{F}{A} \]  
(2.2)

Where \( F \) is hardness (kg cm\(^{-2}\)), \( F \) is the compressive force of the probe (g), \( A \) is the surface area of the probe (cm\(^2\)).

2.2. Statistical Procedures
The measurement data were tested statistically using the SPSS application to see the uniformity of the Levene’s test data with the Least Significant Difference (LSD) test value of 0.05. If the Levene’s Test results show a value of > 0.05 then the data used is homogeneous, if the value of < 0.05 the data is not homogeneous. Then a one-way ANOVA test was conducted to see the effect of storage temperature variations on the physical quality parameters of pineapple fruit and the DMRT (Duncan Multiple Range Test) test to analyze differences in the effect of treatment on parameters of changes in physical quality.

2.3. Mathematical Procedures
Shell color changes, weight loss, and pineapple hardness were analyzed using the 0. order kinetics equation. Ordinary order kinetic equations were used to analyze phenomena in changes in physical quality during storage. The order kinetics 0 analysis equation changes physical quality parameters, are [23]:

\[ C_f - C_i = k t \]  
(2.3)

Where \( C_f \) is the value of the final parameter, \( C_i \) is the value of the initial parameter, \( k \) is the rate constant change in parameter (day\(^{-1}\)), \( t \) is the time of change during storage (day).
2.4. Modeling Physical Quality Changes

Changes in the physical quality of pineapple are modeled using the Arrhenius equation approach with the rate of change constant from the kinetics equation. The Arrhenius equation is [24]:

\[ k = A \cdot e^{-\frac{E_a}{R \cdot T}} \]  \hspace{1cm} (2.4)

Where \( k \) is the rate of change of the Arrhenius (day\(^{-1}\)) constant, \( A \) is the frequency factor, \( E_a \) is the activation energy (J/mol), \( R \) is the gas constanty constant (8.314 J.mol\(^{-1}\).K\(^{-1}\)), and \( T \) is the temperature (K). Equation 2.4 is written in a linear equation (2.5):

\[ \ln k = \left(\frac{-E_a}{R}\right) \left(\frac{1}{T}\right) + \ln A \]  \hspace{1cm} (2.5)

Then the Arrhenius equation is used to predict the value of changes in the parameters of maturity, weight loss, and hardness of pineapple during storage at 10, 12, 18, 20, 22°C.

2.5. Recommended Storage Temperature

From the results of modeling analysis of changes in physical quality (shell color, weight loss, and hardness) of pineapple fruit using the Arrhenius equation can be determined the most optimal storage temperature. According to SNI 3166:2009 the quality of fruit is still good if the percentage of shrinkage is below 10% [25]. From the parameters of changes in physical quality, it can be determined the recommended storage temperature based on product distribution time so that the quality of the fruit is maintained up to the hands of consumers.

3. Result and Discussions

3.1. Effect of Temperature Storage on Physical Quality

After harvesting, pineapple fruit is still undergoing a metabolic process, one of which is a change in skin color due to entering the ripening period. This is evidenced by changes in skin color during storage. In Figure 1. (a) the fastest change in maturity occurs at a storage temperature of 25°C while the lowest change is at storage temperature of 7°C.
The difference in changes in maturity of each variation is caused by differences in temperature, where the ripening process of fruit due to fruit metabolism activity is faster in high temperature rooms. From the research of Hamaisa et al. [26], fruit stored at high temperatures will occur a ripening process that is faster than storing cold temperatures. In addition, high temperature storage will cause the fruit to produce high ethylene so the ripening process will be faster [27].

In Figure 1. (b) shows the highest weight loss of pineapple occurs at storage temperature of 25°C and lowest at 7°C. Weight loss is influenced by several factors, one of which is the process of respiration. The high respiration process will cause water to evaporate so that the water content in the material drops and causes weight loss. While the respiration rate can be influenced by temperature. The higher the temperature of the environment, the higher the respiration process and cause the weight loss to increase. This opinion is reinforced by Pantastico [28,29], where respiration activity is influenced by temperature. If the ambient temperature is high, the process of losing water will be high. According to Winarno [14], every increase in temperature of 10°C will increase the aging rate by 2-3 times faster, so that the water content will decrease faster so that the weight loss increases.

While in Figure 1. (c) shows a decrease in hardness on fruit flesh. The biggest change in hardness occurs in storage temperatures 25°C while the lowest changes at storage temperature 7°C. Muchtadi and Sugiyono [30] explained that decrease in fruit hardness is caused by the content of pectin which begins to dissolve in water due to the process of reforming complex compounds so that the fruit becomes soft. Research from Simson et.al. [10] informed that if temperature storage too high will cause the fruit density decrease dramatically during storage.

3.2. Statistical Analysis

The first step in the statistical test is to conduct a Levene’s test to determine the homogeneity of the data used with a limit of LSD values of 0.05. Then, oneway ANOVA test to see the effect of storage temperature on physical quality parameters (Table 3). The last DMRT test was carried out to see the difference in effect of storage temperature variations on changes in physical quality parameters on pineapple (Table 4.).

| Table 3. Oneway ANOVA test on the physical quality parameters of pineapple on the 16th day |
|-------------------------------------------------|
| Sum of Squares | df | Mean Square | F   | Sig. |
| Shell Color Between Groups | 17816,427 | 2 | 8908,214 | 31806,214 | 0,000 |

Figure 1. (a) Changes of shell color during storage (b) changes of percentage weight loss during storage (c) changes of hardness during storage at (o)7°C, (∆)15°C, (∗)25°C
Within Groups 1,680  6  0,280
Total 17818,108  8

| Weight Loss | Between Groups | 193,389 | 2 | 96,695 | 29,760 | 0,001 |
|-------------|----------------|---------|---|--------|--------|-------|
|             | Within Groups  | 19,495  | 6 | 3,249  |        |       |
|             | Total          | 212,884 | 8 |         |        |       |

| Hardness    | Between Groups | 1,015   | 2 | 0,507  | 9,330  | 0,014 |
|-------------|----------------|---------|---|--------|--------|-------|
|             | Within Groups  | 0,326   | 6 | 0,054  |        |       |
|             | Total          | 1,341   | 8 |         |        |       |

From Table 3. Shows that storage temperature affects changes in the physical quality parameters of pineapple. This is indicated by the significance value <0.05. In Table 4 shows the difference in changes by variations in storage temperature on physical quality parameters of pineapple. In response to the effect of storage temperature on changes in color shell parameters the temperature of 15°C is not different from the storage of 25°C and both are different from the storage temperature of 7°C. In weight loss parameters, the effect of storage on weight loss at 7 and 15°C is not different, and the two treatments are different to storage temperature 25°C. From hardness parameters, the effect of storage temperature on decreasing fruit hardness temperature 25°C and 15°C is not different while the two treatments different from temperature storage at 7°C.

**Table 4.** DMRT test on the physical quality parameters of pineapple on the 16th day

| Physical quality parameters | Storage | N  | Subset     |
|-----------------------------|---------|----|------------|
|                             | 7 °C     | 3  | 5,6167^a   |
| Shell color                 | 15 °C    | 3  | 100,00^b   |
|                             | 25 °C    | 3  | 100,00^b   |
| Weight loss                 | 7 °C     | 3  | 3,0567^a   |
|                             | 15 °C    | 3  | 5,5500^a   |
|                             | 25 °C    | 3  | 13,8967^b  |
| Hardness                    | 25 °C    | 3  | 1,9823^a   |
|                             | 15 °C    | 3  | 2,2497^a   |
|                             | 7 °C     | 3  | 2,7897^b   |

Number followed by the letter of superscript (^a and ^b) in the same column mean significantly different from the DMRT comparison variety based LSD_{0.05} test.

3.3. **Statistical Analysis**
Figure 2. (a) Constant value (k) the rate of change in shell color parameters, (b) changes shell color observation and prediction of time, (c) the validation test of observation on the prediction data of shell color during storage at (o) 7°C observation, (A) 15°C observation, (×) 25°C observation, (---) 7°C prediction, (—.—) 15°C prediction, (-----) 25°C prediction.

For kinetics analysis on changes in the physical quality parameters of pineapple fruit (shell color, weight loss, and hardness) using the order kinetics 0 equation. The rate constant changes the physical quality parameters of pineapple fruit displayed in Figure 2.

From Table 5 indicates the rate constant changes in the parameters of pineapple with the highest value at a storage temperature of 25°C and the lowest value at a storage temperature of 7°C. After that, the predicted value of changes in each physical quality parameter of pineapple fruit was tested and validated to determine whether the modelling equation could be used by looking at the value of R^2.

| Physical quality parameters | Storage | k     | R^2  |
|-----------------------------|---------|-------|------|
| Shell color (%.day⁻¹)       | 7°C     | 0.1939| 0.5529 |
|                             | 15°C    | 0.2683| 0.9038 |
|                             | 25°C    | 0.7837| 0.8553 |
| Weight loss (%.day⁻¹)       | 7°C     | 0.1939| 0.9540 |
|                             | 15°C    | 0.2683| 0.9118 |
|                             | 25°C    | 0.7837| 0.9747 |
| Hardness (kg.cm⁻².day⁻¹)    | 7°C     | -0.0679| 0.6610 |
|                             | 15°C    | -0.1013| 0.8565 |
3.4. *Arrhenius Analysis*

From the value of the rate constant changes in the physical quality parameters of pineapple fruit, we can find the predicted value of the rate constant of changes in parameters at other storage temperatures by making a linear graph between 1/T (K) for ln (k) for each physical quality parameter as shown in Figure 3.

![Figure 3. Relation between 1/T (K) to Ln (k) Shell color of Pineapple Fruit](image)

From Figure 3, we find a linear equation $y = bx + a$, with values $b = -12530$ and $a = 44,441$. Because $bx = (E_a/R) (1/T)$ and $a = \ln(A)$ so, the value of $E_a = bR$ and $A = e^a$ and that the $E_a$ value = $-1,042 \times 10^5$ and $A = 1,997 \times 10^{19}$. $E_a$ value (activation energy) shows the minimum energy value that must exist in the system to carry out reactions in the metabolic process, an example of this process is a change shell color. Figure 4.26. shows $R^2$ value of 0.7985 so that this modeling can be used because the validation value approaches the value is 1. The values of $A$, $E_a$, and $R^2$ in the other physical quality parameters are presented in Table 6.

![Table 6. Value A, Ea, and R² Each parameter of the Arrhenius equation](image)

| Physical quality parameters | A         | $E_a$ (kg.mol⁻¹.K⁻¹) | $R^2$ |
|----------------------------|-----------|-----------------------|-------|
| Shell Color                | 1,997$\times 10^{19}$ | -1,042$\times 10^5$  | 0,798 |
| Weight loss                | 2,554$\times 10^9$   | -5,454$\times 10^4$  | 0,937 |
| Hardness                   | 2,213$\times 10^3$   | -2,411$\times 10^4$  | 0,960 |

After obtaining the $E_a$ and $k$ constant values in the Arrhenius equation then determine the value of the rate constant change ($k$) parameter at the other temperature variations with the equation $k = A(\exp(-E_a/RT))$. The value of the rate constant changes ($k$) physical quality parameters in other temperature variations are shown in Table 7.

![Table 7. Value of constant (k) change rate Arrhenius prediction of other temperature variations.](image)

| Temperature (°C) | Shell color (% day⁻¹) | Value of constant (k) change rate |
|------------------|------------------------|----------------------------------|
| 7                | 0,7520                 | 0,1730 -0,0706                    |
| 10               | 1,2078                 | 0,2217 -0,0788                    |
| 12               | 1,6474                 | 0,2609 -0,0847                    |
| 15               | 2,6031                 | 0,3315 -0,0942                    |
| 18               | 4,0746                 | 0,4191 -0,1044                    |
After knowing the constant rate (k) of Arrhenius predictions in other temperature variations, then look for the value of Arrhenius prediction changes in the physical quality parameters of pineapple fruit to the time function as shown in Figure 4 and Figure 5.

### Figure 4. Arrhenius’s prediction changes in shell color parameter against day of storage at (□) 7°C, (◊) 10°C, (∆) 12, (×) 15°C, (*) 18°C, (▬) 20°C, (o) 22°C, (+) 25°C

### Figure 5. Arrhenius’s prediction changes in weight loss and hardness parameter against day of storage at (□) 7°C, (◊) 10°C, (∆) 12, (×) 15°C, (*) 18°C, (▬) 20°C, (o) 22°C, (+) 25°C

3.5. Recommendation for Temperature Storage

An example of modeling for shell color for pineapple distribution from Lampung to Surabaya takes 3 days using a container truck and it is desirable that the destination still has a maximum shell color maturity value is 5%, the minimum fruit hardness parameter is 2.00 kg.cm\(^{-2}\), and maximum weight loss of 10% according to SNI 3166:2009. The value of changes the parameters every time can be seen in the Arrhenius prediction table for each temperature variation of the time function. In the table can be seen if with the above conditions, then the storage temperature in the container that meets that is at a storage temperature of 7-12°C. However, to avoid cost that are too high for lowering temperatures and to prevent chilling injury, storage at 10-12°C is more recommended.
4. Conclusion

Based on the results of this study, it can generally be concluded that the storage temperature affects the changes in the physical quality parameters of pineapple during the storage process, besides, it can be concluded:

1. The results showed changes in low temperature storage are: shell color 0.00-10.67 %, weight loss 0.00-3.70 %, hardness 3.955-3.062 kg.cm^{-2}. Control treatment: shell color 0.00-100 %, weight loss 0.00-13.89 %, hardness 3.898-1.982 kg.cm^{-2}.

2. Constant (k) kinetics at low temperature are: shell color 0.4921-5.6901 %.day^{-1}, weight loss 0.1939-0.2683 %.day^{-1}, hardness (-0.0679)-(-0.1013) kg.cm^{-2}.day^{-1}. Control treatment: shell color 7.7994 %.day^{-1}, weight loss 0.7837 %.day^{-1}, hardness -0.1276 kg.cm^{-2}.day^{-1}.

3. The values of A and Ea (in J.mol^{-1}.K^{-1}) Arrhenius are: shell color 1.997x10^{19} and -1.0427x10^{5}, weight loss 2.554x10^{9} and -5.454x10^{4}, hardness 2.213x10^{3} and -2.411x10^{4}.

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