Kinetics analysis of the effect of types and concentrations of ripening agents on the physical quality changes of banana fruit (*Musa acuminata* Colla)

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**Abstract.** Nowadays there are many fruit ripening agents available in the market, thus, it is important to know the performance of those ripening agents in applications. This research determined the effect of the type of ripening agents and applied concentrations on the physical changed of banana during ripening process. Ethylene, acetylene, and ethephon in three different concentrations of 0, 250, and 500 ppm were investigated in a 3x3 factorial with three replications. Green mature bananas were treated with those ripening agents in closed boxes, after being treated then stored in the open ambient room until they were ripened. Weight loss, soluble solid content, and firmness of the samples were monitored every 12 hours until the samples were ripened. Results indicated that in the three ripening agents, the changes of weight loss, soluble solid content, and firmness followed zero, first, and second order kinetics equations, respectively. In general, the values of constant rate of change for weight loss and firmness increased with the concentration but not for soluble solid content. Statistical analysis indicated that the type of ripening agent significantly affected the k values of weight loss, soluble solid content, and firmness.

1. **Introduction**

Banana is one of the horticultural commodities that dominates the fruit market [1]. Its sweet taste and affordable price make this fruit popular among people. In addition, banana is a very easy to cultivate [2], thus, the banana production to remain high every year. Banana production in Indonesia increases over the past three years. In 2016, Indonesia produced 7 tons of bananas, two years later, in 2017 and 2018, banana production increased to 7.16 tons and 7.26 tons, respectively [3].

Banana mas (*Musa acuminata* Colla) is one of the banana variants [4], although it does not as famous as banana ambon (*Musa acuminata cavendish*). Banana mas is classified as climaeretic type fruits, which is the fruit group that increases the ethylene production during the ripening process [5]. It will continue to ripe after being harvested, therefore it should be harvested in unripe or mature condition but the skin is still in a green color [6]. In this mature green condition, banana can be stored for longer period as the storage condition fulfil the requirements for maintaining green quality condition of banana. However, as the banana has to be sold in the market or displayed on the shelf of a fruit store or supermarket, green color skin banana will not be attractive for the consumer.

For that reason, banana should be ripened, particularly to alter the skin color from green to yellow condition. Traditionally, banana is squeezed before banana being sold [7]. However, bananas that are
allowed to ripe naturally, generally result in a non-uniform color skin which give an unattractive appearance for the consumer. Some efforts have been developed to improve ripening process in banana postharvest handling. Several ripening agents such as ethylene, acetylene, and ethephon have commonly been used to improve ripening process of climacteric fruits including banana.

These three ripening agents have generally been used by the farmer or the trader, however, the results are still not yet optimal. Several studies have been conducted to determine the influence of these three ripening agents on the ripening of bananas, such as the application of ethylene gas in banana Susu (Musa acuminata Var Silk) [8], the application of acetylene gas in banana Ambon [9], and the application of ethephon in banana barangan (Musa acumint L) [10]. The results showed a significant change in maturation speed due to the application of these three substances. However, there exist discrepancies including the concentrations, exposure duration, and application methods. There is lack of information regarding the comparison of the performance of these ripening agents in kinetics changes of ripened bananas. The purpose of this study was to determine the effect of the types and concentrations of ripening agents on some physical properties of banana mas during ripening process kinetically and statistically.

2. Materials and methods

The samples used in this study was green mature banana mas obtained from fruit trader at Wonosari, Yogyakarta, Indonesia. The samples were selected for homogeneous in size, color, shape and free from defect and disease to be used as the samples. This research was conducted in two-way Completely Randomized Design, factorial 3×3 with three replications and the means comparison was tested using Duncan’s Multiple Range Test (DMRT). The first factor was the type of ripening agents, consisted of ethylene gas, acetylene gas, and ethephon liquid (Bayer Ethrel 480SL). The second factor was the concentration of each type of ripening agents consisted of 0 ppm (control), 250 ppm, and 500 ppm.

The experimental procedures for ethylene and acetylene applications were as follow: banana samples were loaded into an airtight plastic container, then the gas either ethylene or acetylene at desired concentrations were injected into the containers using syringe. The samples were then stored for one day at ambient room temperature (28°C). After that, the containers were opened and banana samples were taken out and allowed to ripe in another open plastic basket at ambient room until reach ripe condition for 7 days. The application of ethephon was carried out as follow: ethephon was added with distilled water to create the three desired concentrations of 0 ppm (without ethephon as control), 250 ppm, and 500 ppm. Banana samples were then immersed in those ethephon solutions for 5 minutes. After that, the samples were allowed to dry, then stored in an airtight plastic container for a day. Those samples were then taken out and stored at an ambient room for 7 days or until they reach ripe condition.

Three physical qualities of the samples, namely weight loss, soluble solid content, and firmness were measured every 12 hours at the morning and evening for 7 days. Weight loss was determined by weighing certain banana sample using digital balance (Idelife IL-500C) with ±0.1g precision measurement. Firmness was determined by compressing a cylindrical sample slice of 1 cm thick using compression machine equipped with loadcell (LGT, Type LAS-100kg) and an interface (Loadstar LV-1000) to connect to the computer. The soluble solid content of the samples was measured using refractometer (Pal-α, ATAGO) with a measurement range of 0-85%.

3. Result and discussion

3.1. Weight loss

The observed data of weight changes of measured samples showed a linear decline trend. From kinetics analysis it was found that the trend of data changes followed zero order kinetic reaction. Therefore, equation 1 was used to determine the rate constant values of weigh losses of the samples [11].
\[ C_t = \pm k t + C_0 \quad (1) \]

\( C_t \) was the weight of banana samples at any time (g), \( k \) was the value of rate constant of weight loss (g/hour), \( t \) was the measurement time (hours), and \( C_0 \) was the initial weight of bananas (g). Table 1 shows the averages of the calculated rate constants (k) for all treatment combinations. Other study reported that the change of weight loss of strawberry (\textit{Fragaria x ananassa}) also followed zero order kinetics equation [12]. In general, \( k \) values increased with concentrations and ethylene resulted the largest weight loss, while ethephon was the smallest. Negative values indicated that the weight of the samples decreased along with the time [13]. The \( k \) values changed according to the type of ripening agent and the concentration. In general, \( k \) values of weight loss increased with the increase of concentration. This indicated that ripening agents could actually trigger the ripening process of banana samples.

**Table 1.** The average of rate constant values of weight loss (g/hour)

| Type      | Concentration | Concentration | Concentration |
|-----------|---------------|---------------|---------------|
| Ethylene  | -0.1143       | -0.1160       | -0.1167       |
| Acetylene | -0.1018       | -0.1065       | -0.0984       |
| Ethephon  | -0.0712       | -0.1005       | -0.1104       |

Statistical analysis confirmed that both the type and concentration of ripening agents significantly affected the values of rate constant (P<0.05), but the interaction of those two factors were not significant. Table 2 shows mean comparison of \( k \) values of weight loss using DMRT according to the type and concentration of the ripening agent. According to the type of ripening agent, the largest \( k \) value was for acetylene and the smallest was for ethylene (P<0.05). This finding indicated that by using acetylene, the weight loss was faster than using ethylene, or ethylene might capable to inhibit larger weight loss during ripening process. Other researcher reported that acetylene and ethylene produced no significant different of weight loss in banana barangan but significantly different to ethephon [14].

**Table 2.** DMRT results of rate constant values of weight loss

| Type      | k (g/hour) | Concentration | k (g/hour) |
|-----------|------------|---------------|------------|
| Acetylene | -0.110544a | 0 ppm         | -0.117650a |
| Ethephon  | -0.108900ab| 250 ppm       | -0.102211ab|
| Ethylene  | -0.091938b | 500 ppm       | -0.094378b |

The values followed by the same letter in the same column were not significant different

According to the concentration, the application of ripening agents 500 ppm resulted in the smallest \( k \) values and significantly differed with the control (P<0.05). This implied that larger concentration of the ripening agents would capable to ripe banana with minimum loss in the weight.

3.2. Soluble solid content

The change of soluble solid content along with ripening time showed a nonlinear pattern, graphical plot of natural log base of soluble solid content against measurement time was found to create a linear trend line. This indicated that the changes of soluble solid content of the samples followed first order kinetics equation. Using an analogy of Newton Law of Cooling, the form of the first order kinetics equation used to calculate the rate constant of soluble solid content changes as shown in equation 2 [13].

\[ Ln \left( \frac{C_t - C_e}{C_0 - C_e} \right) = \pm k \cdot t \quad (2) \]
Where $C_t$, $C_o$, and $C_e$ were the soluble solid content values at any certain time, at initial conditions, and in the equilibrium state, respectively (°Brix), $k$ was the reaction rate constant (1/hour), and $t$ was the measurement time (hours). First order kinetics equation in that form was also used to evaluate the change of soluble solid content of tomato (Solanum lycopersicum) [15] and strawberry (Fragaria x ananassa) [12].

Table 3. The average of rate constant values of soluble solid content (1/hour)

| Type       | Concentration |
|------------|---------------|
|            | 0 ppm | 250 ppm | 500 ppm |
| Ethylene   | 0.0113 | 0.0112  | 0.0118  |
| Acetylene  | 0.0108 | 0.0112  | 0.0106  |
| Ethephon   | 0.0078 | 0.0097  | 0.0098  |

The soluble solid content of all treatments increased with the time and finally reach a constant value. The changes of soluble solid content were larger at the initial period of ripening until 20-hour ripening process, then gradually decreased and finally reach a constant value after around 40 hours. The values of $k$ changed with the concentration, but it did not follow any certain pattern. While at the same concentration, the $k$ values of ethylene seemed to have the largest values, this indicated that ethylene might possible to produce larger sugar content during ripening process than acetylene and ethephon.

The type of ripening agent affected $k$ values of soluble solid content (P<0.05), while concentration and its interaction with the type had no significant effect on $k$ values of soluble solid content. The type of ripening agents (ethylene, acetylene, ethephon, and calcium carbide) had a significant effect on total soluble solid content, total acid, and vitamin C of banana barangan [14].

Table 4. DMRT results of rate constant values of soluble solid content

| Type        | Concentration | 1/hour |
|-------------|---------------|--------|
| Ethephon    | 0 ppm         | 0.009244<sup>a</sup> |
|             | 250 ppm       | 0.010675<sup>a</sup> |
| Ethephon    | 500 ppm       | 0.010800<sup>a</sup> |
| Acetylene   | 0.010889<sup>ab</sup> |
| Ethylene    | 0.012238<sup>b</sup> |

The values followed by the same letter in the same column were not significant different.

Ethylene had the largest $k$ value and significantly different with ethephon (P<0.05). This confirmed that ethylene might produce higher soluble solid content or would convert more starch to sugar than ethephon during ripening process. It was also reported that the use of ethylene on banana barangan produced the highest soluble solid content as compared to acetylene and ethephon [14].

3.3. Firmness

The trend of firmness changes along with the time showed non-linear pattern with a very sharp decrease changes at the initial period of ripening mostly before 20 hours of ripening process, then soon reach nearly constant values for all treatments. The graphical plot showed that natural logarithmic of firmness values against ripening time showed non-linear pattern, this indicated that the change of firmness followed second order kinetics equation. Therefore equation (3) was used to calculate $k$ values of samples firmness [11]. It was also reported that the change of firmness of mango fruit (Mangifera indica cv. ‘Nam Dok Mai Si Thong’) followed second order kinetics equation [16].

\[
\frac{1}{C_t} - \frac{1}{C_o} = \pm k \cdot t
\]  

(3)

Where $C_t$ and $C_o$ were the firmness values of bananas at any time and at the initial condition respectively (kgf/cm²), $k$ was the rate constant value of firmness change (1/(kgf.hour/cm²)) and $t$ was
the time (hours). Table 5 shows the results of k values of firmness changes during ripening process for all treatments evaluated. There was a trend of increase in k values with concentration for acetylene and ethephon, but not for ethylene which was almost constant. At the concentration of 250 ppm and 500 ppm, acetylene was always the largest while ethephon was the smallest. This might indicate that the use of acetylene created faster firmness decrease than the other ripening agents, whereas ethephon was the best in retaining sample firmness.

Table 5. The average of rate constant values of firmness (1/kgf.hour/cm²)

| Type     | Concentration | 0 ppm  | 250 ppm | 500 ppm |
|----------|----------------|--------|---------|---------|
| Ethylene |                | -0.1114| -0.0943 | -0.1046 |
| Acetylene|                | -0.1026| -0.1151 | -0.1286 |
| Ethephon |                | -0.0714| -0.0805 | -0.0807 |

Statistical analysis resulted that the only the type of ripening agent which significantly affected samples firmness (P<0.05), while concentration and its interaction with the type of ripening agent had no effect on sample firmness. It was also reported that different concentration of ethylene had no significant effect on pulp firmness of banana cv. ‘Dwarf Cavendish’ [17].

Table 6. DMRT results of rate constant values of firmness

| Type       | k (1/kgf.hour/cm²) | Concentration | k (1/kgf.hour/cm²) |
|------------|---------------------|---------------|---------------------|
| Ethephon   | 0.076822^a          | 0 ppm         | 0.099613^a          |
| Acetylene  | 0.116333^b          | 250 ppm       | 0.104600^a          |
| Ethylene   | 0.110913^b          | 500 ppm       | 0.098600^a          |

The values followed by the same letter in the same column were not significant different

Table 6 shows that ethephon had the smallest k value and significantly differed with ethylene and acetylene. As mentioned above, this meant that ethephon would be the best in retaining sample firmness during ripening process, while ethylene and acetylene were approximately the same. It was also reported that ethephon had the largest firmness value and significantly differed with ethylene and acetylene for banana barangan [14].

4. Conclusion
In both the three ripening agents, the change of weight loss, soluble solid content, and firmness followed zero, first, and second order kinetics equations respectively. In general, the values of constant rate of change for weight loss and firmness increased with the concentration but the same was not true for soluble solid content. The type of ripening agent significantly affected the k values of weight loss, soluble solid content, and firmness. Concentration only affected weight loss, while the interaction between the type and concentration were not found in both the three parameters evaluated.

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