Mathematical analysis the effect of traffic bump shocking and layer position on the physical properties of Strawberry fruit \((Fragaria \times ananassa)\) during transportation

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Abstract. Strawberry is known as a perishable fruit, it is very easy to be damaged as the effect of mechanical force, and this is one of the main problem in postharvest of this fruit. In Indonesia, it is often encountered a traffic bump across the road, this may create a shocking force that may affect the damage of the fruit during transportation. This research was intended to find out the effect of duration of shocking and layer position in the packing box on the physical properties of strawberry fruit. Application of shocking force was done using a special shocking apparatus to the strawberry samples inside wood package box which was arranged in three layers for a certain determined time. After shocking process the sample were then stored at room temperature and continuously monitored. It was found that both the duration of shocking and layer position in the box were significantly affect some of physical properties of the fruit, such as respiration rate, weight loss, brix content, firmness, and lightness of the fruit. The rate of change of physical properties of the fruit could be described appropriately using kinetics model of the zero or first order.

1. Introduction

Strawberry \((Fragaria \times ananassa)\) is known as one of the most important fruit commodity in the world. Although this plant is a subtropical origin, but lately it has been cultivated in tropical area such as Indonesia. However, in Indonesia generally strawberry can only be cultivated at 1000 – 1500 m asl and its quality is not good enough. It is often encountered strawberry with sour taste, non-uniform color, greatly vary in size, and undesirable defects on the fruit. This indicates that in both cultivation and postharvest areas still need much more research to improve strawberry farming system.

Strawberry is one of a non-climacteric fruit, therefore this fruit should be harvested when it has been ripe in order to have the highest quality in terms of flavor, taste, and color. A ripe strawberry has very thin skin and it is easily to be damaged by mechanical force. As stated by Kuchi and Sharavani [1] that ripe strawberry bruise very easily. The pericarp of a strawberry is so soft that workers must harvest the fruits carefully to avoid damage. This phenomenon to be one of the most important problem in strawberry postharvest handling practices. Damaged skin of strawberry will easily to deteriorate through the infection of microbes or become susceptible to increase the respiration rate which may spur high metabolism. Bruise damage is commonly a mechanical damage of fresh produce and occurs in all stages of postharvest handling, particularly packinghouse operations, transport and storage [2]. Ferreira et al.
stated that strawberry bruising starts in the field and is more likely induced by compression stress during harvest, field pack and subsequent handling operations. Some phenomenon may cause mechanical force to the fruit. It may come from the equipment used to handle strawberry, human force who handle the strawberry, or others external forces. One of important source that should be considered is the shocking force that may occur during transportation of ripe strawberry.

Road condition such as holes, bumpy, and traffic bump may give serious mechanical force to the fruit. When transported strawberry pass a traffic bump a shocking force will be resulted to the fruit. The fruit may collide each other or it may hit to the container wall, and if this shocking force quite high or it may occur in a long duration it is possible to cause the fruit to be damaged. On the other hand, layer position of strawberry in the container may have significant effect to the magnitude of damage. The fruit which near the wall or at the base of the container may have higher shocking force than the one at the center, and so it may has more severe damage than the other. Fischer et al. [4] stated that under certain transport conditions, when the force of the vibrations approaches the force of gravity, the strawberries become virtually weightless in their containers. In this state, they bump together and rub against each other as they rotate. This contact results in a type of damage called “roller bruising”. To following research was intended to investigate the effect of duration of shocking and layer position in the packing box to the rate of quality deterioration of strawberry fruit.

2. Materials and Methods

2.1. Materials
Freshly strawberries were bought from West Java, Indonesia through fruit trader. These strawberries were transported in a thick polystyrene box at night and came to the laboratory at the morning. Strawberries were then qualitatively selected based on color, size, and absence of defects to obtain a homogeneous sample. Selected strawberries were than cleaned carefully using soft wetted tissue paper and measured some of its physical properties before experiment was carried out. It was found that average length of a single strawberry fruit was 2 - 4 cm and the diameter was 1 - 2 cm with the weight of 8 - 10 g. Initial brix content of the sample was 5 - 6% with the firmness of 4 - 4.5 kgf, and totally 6000g of strawberries were needed in the research.

2.2. Methods
The main apparatus used in this research was a model of shocking table made from steel which was similar as a mortar flow table test (ASTM C1437) driven using 0.25 hp electric motor. It consisted of a table with the diameter of 25 cm and weight of 300 g. This table was supported by a vertical shaft which was further connected to another horizontal shaft which had a specially constructed pulley head. During operation, when the horizontal shaft rotated, the table would be raised and then suddenly dropped with the drop height of 1.5 cm. This drop would create a shocking force with the acceleration of 5.2G. In the following research the speed of the horizontal shaft was kept constant of 60 rpm. A wood container of 24 x 20 x 18 cm outer dimensions was used as packing box to place the sample to be tested. Strawberry to be tested was loaded into the wood container in three layers, the wood container was then put on the apparatus table. The electric motor was then started and the table along with the sample would start to rise and drop continuously until certain determined time. The following research used factorial 3 x 3 in Completely Randomized Design. As the first factors were duration of shocking i.e. 2, 4 and 6 minutes, while the second factors were the position of fruit layer in the wood container i.e. lower, middle, and top layer. In every treatment combinations the wood container was only filled in three layers of strawberry fruit with the total weight of about 200g. Every treatment combinations were replicated three times. As a comparison, it was also used a control sample which had no shocking treatment. After shocking process then strawberry were put into another container and stored at the room temperature in the laboratory. Some of the physical properties such as weight loss, brix, firmness, color, and respiration rate were measured periodically. For measuring respiration rate, it was done using static method with a self constructed respirometer made from thick plastic jar 11.5 cm in diameter and 11.8 cm height.
small hole around 1 cm in diameter was made on the cap of the jar, the hole was the closed using rubber sheet and glue. Gas concentration inside respirometer were measured periodically using O$_2$ and CO$_2$ Gas Analyzer (Quantek 902D). Firmness of the sample was measured using a compression machine equipped with a load cell (RAS1-10KS-S-CO3) and USB load cell interface (Loadstar Sensor DI-1000U) which could be connected directly to the computer. The other equipment were color meter (TES 135A), Refractometer (ATAGO Pal-α), and digital balance (MH-Series, accuracy 0.00g) for measuring color change, brix content and weight of the fruit sample respectively.

3. Results and Discussion

3.1. Respiration rate

Figures 1 shows an example of respiration rate expressed in oxygen consumption (R$_{O2}$) for the bottom layer of strawberry during 48 hours storage period for the three shocking durations. It was found that R$_{O2}$ decreased with time, while the shortest shocking period tended to have the lowest respiration rate and vice-versa. This indicated that the longer duration of shocking would create higher respiration rate, and this subsequently would create more severe deterioration to the fruit.

![Figure 1. Respiration rate (R$_{O2}$) for the bottom layer of the three shocking durations](image)

Statistical analysis indicated that both shocking duration and layer position were significantly affect R$_{O2}$, while there was no interaction between them. The mean comparison using DMRT indicated that shocking for 6 minutes had the largest R$_{O2}$ and differed from 2 and 4 minutes, while for 2 and 4 minutes were not significant different. However it was found that there was a trend that as the shocking duration increase R$_{O2}$ would increase too.

According to the layer position, it could be seen that R$_{O2}$ for the bottom layer had the largest value and significantly differed from the middle and upper layers, while for middle and upper layer were not different. It was suggested that the bottom layer suffered the largest overload from the above fruit sample and also directly contact with the wood box, so it received the most severe shocking force. Such condition might be caused more damage to the fruit and finally created higher respiration rate. Respiration rate of the bottom layer fruit treated with 6 minutes shocking duration, increased 22.1% as compared to control and was found significantly different from t-test analysis. Barrios et al. [5] found that respiration rate of strawberry in 20.2±1.6 O$_2$ and 0.00±0.01 CO$_2$ concentrations in 23°C storage room temperature was reported to be 74.7±3.94 ml/kg.hr after being monitored for 4 hours. This value was nearly same as the result found in this research.

3.2. Weight loss
Figures 2 depicts an example of percentage weight loss curves for the three layers at 6 minutes shocking duration during storage. Percentage weight loss increased with storage time, the same phenomenon were also observed for the others treatments. The largest weight loss tended to occur for the longest shocking duration and the lowest for control.

![Percentage weight loss for the bottom layer of the three shocking duration](image)

**Figure 2.** Percentage weight loss for the bottom layer of the three shocking duration

Statistical analysis indicated that only layer position was known to have significant effect to the weight loss, while shocking duration and the interaction between them had no effect. Further analysis (DMRT) resulted that the highest weight loss occurred for the bottom layer, but not differed with the middle one while significantly differed with the upper layer, it was almost the same phenomenon as for \( R_{O2} \). This indicated that as the fruit received more severe shocking force, it would create higher respiration rate and subsequently resulted in higher loss of water including from transpiration, and finally created the largest weight loss. Percentage weight loss of the bottom layer increased 12.1%; 25.9%, and 27.7% higher than control for shocking duration 2, 4, and 6 minutes respectively.

Kinetics analysis resulted that the rate of weight loss of fruit sample followed zero order. The values of rate constant were 0.272 to 0.363 \%/hr, being the lowest for control and the highest value for the bottom layer at shocking duration 6 minutes. The goodness of fit of the tested mathematical model to the experiment data was evaluated from the coefficient of determination \((R^2)\), and gave the values ranged from 0.97 to 0.99. Van de Velde et al. [6] also used general kinetics equation of zero or first orders to find rate reaction constants to fit the experimental data. Although they used it for individual anthocyanin degradation in strawberries stored in 70kPa O\(_2\) + 20kPa CO\(_2\) not for weight loss. However, it could be used as a clue that the change of other properties of strawberry fruit might follow those orders.

### 3.3. Total color difference

Figure 3 shows the typical graph of total color difference, in which the values of total color difference increased with stored time for all treatments investigated. Statically both shocking duration and layer position had significant effect to the value of total color difference, however there was no interaction observed. Further analysis indicated that the longest shocking duration and the bottom layer created the largest values of total color difference and significantly differed with the other treatments. Castello et al. [7] reported that total color difference of the external face (skin) of fresh cut strawberry increased with time. The value was found to be around 8 after being stored for 2 days in 10°C room temperature. This value was almost the same as ones found in the following research that was 8.7. Buve et al. [8] also found the same trend of increment of total color difference for strawberry juice stored in the bottle at 20 to 35°C room temperatures. The rate constant values of total color difference were found to follow kinetics zero order with the values ranged from 0.102 to 0.188 hr\(^{-1}\). The coefficient determination of the resulted prediction equations were 0.91 to 0.99.
3. 4. Firmness

Figure 4 shows an example graph of the change of fruit firmness during stored period for the bottom layer sample which was subjected to shocking duration 6 minutes. It could be seen that the firmness of the fruit sample rapidly decreased with stored time. At this layer, firmness of the sample decreased 34%; 64%, and 68% from the initial value for shocking duration of 2, 4, and 6 minutes respectively. As the result of shocking force, the fruit tissue damaged and this in turn would fasten respiration rate and these two causes were the major reason of the rapid decreased of the fruit firmness.

Both the shocking duration and layer position significantly affect fruit firmness, while they were no interaction between them. Further analysis indicated that the bottom layer had the lowest firmness value and significantly differed with the middle and upper layers. As compared with control, firmness of this bottom layer decreased 19.3%, 21.8%, and 33.3% for shocking duration of 2, 4, and 6 minutes respectively. The rate of firmness change was found to follow first order with the values of rate constants ranged from 0.0056 to 0.0077 hr$^{-1}$. The same as the other evaluated parameters above that the largest rate constant occurred for the bottom layer with the longest shocking duration. Resulted prediction equations were also had quite high R$^2$ ranged from 0.88 to 0.98. As the comparison, Castello et al [7] reported that force at failure of fresh cut strawberry was 10 N and decreased to around 7.5 N after being stored for 6 days in 10°C room temperature. These results were smaller than ones found in the research carried out as the result of the different sample condition used. In the following research force at failure
was measured using whole strawberry fruit and gave the values of around 40 to 50 N at the beginning and decreased to around 20 to 25 N after being stored for 6 days.

3. 5. Brix
Percentage brix of the sample tended to decrease with stored time, however the rate of that reduction seemed to be slower as compared to the other investigated parameters (Figure 5). Zeb et al. [9] also found that the same phenomenon for strawberry without any treatment stored at ambient temperature, showed the value of brix decreased with time.

![Figure 5](image_url)

**Figure 5.** The change of fruit brix values for the bottom layer sample of the three shocking duration

The only shocking duration was found to have an effect to the brix, while layer position and the interaction had no significant effect. Mean comparison analysis indicated that 6 minutes shocking duration had the smallest brix value and differed significantly from the two other shocking times. The values of rate constant were found using first order kinetics equation and ranged from 0.0015 1/hr for control to 0.0025 hr⁻¹ for the bottom layer subjected to 6 minutes shocking duration. The resulted predition equations had quite high goodness of fit with the experimental data at the order of 0.78 to 0.98.

3. 6. Parameter correlation
Some of the above measured parameters including shocking time duration (y), brix (x₁), weight loss (x₂), firmness (x₃), and total color difference (x₄) could be correlated using multiple linear regression to give a simple mathematical relationship which might be used to predict critical shocking duration for each layers (Table 1).

| Layer position  | Equations                  |
|-----------------|----------------------------|
| Upper Layer     | y = 1,032 x₁ - 0,192 x₂ + 1,109 x₃ + 2,675 x₄ - 8,309 |
| Middle Layer    | y = -0,0564 x₁ + 0,668 x₂ + 0,686 x₃ + 0,789 x₄ - 12,491 |
| Bottom Layer    | y = -0,0128 x₁ + 0,316 x₂ + 0,7665 x₃ + 1,0306 x₄ - 9,676 |

Table 2 shows predicted critical shocking duration for 5, 10, and 15% fruit quality deterioration respectively. For example for the upper layer, quality of the fruit at this position will decrease 5%/day if those fruits are subjected to shocking duration of 4.49 minutes.
Table 2. Critical shocking duration (minute) for the three layers

| Layer Position | Percentage Quality Deterioration (%/day) |
|----------------|-----------------------------------------|
|                | 5%          | 10%         | 15%          |
| Upper Layer    | 4.49        | 17.29       | 30.10        |
| Middle Layer   | 1.05        | 14.60       | 28.15        |
| Bottom Layer   | 0.85        | 11.39       | 21.92        |

4. Conclusions
a. Shocking duration and/or layer position significantly affected the investigated parameter, however no interaction effect was found on the investigated parameters.
b. In general bottom layer of the sample with longest shocking duration suffered the most severe damage and tended to have the largest rate of change.
c. The rate of change of the observed parameters with time could be explained using general kinetics equation of zero or first order with satisfactorily goodness of fit.
d. Simple equations to calculate critical shocking duration were developed involved brix, weight loss, firmness, and total color difference.

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