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Modeling of Sapodilla Fruit (*Manilkara zapota* (L.) van Royen) Terminal Velocity in Water

Andasuryani^{1*)}, Renny Eka Putri¹⁾

¹⁾ Agricultural Engineering Dept., Andalas University, Padang, 25163, Indonesia

E-mail: andasuryani@ae.unand.ac.id

Abstract

Terminal velocity is one of the hydrodynamic fruits properties that significant in the development of sorting equipment. The study aimed to determine terminal velocity of sapodilla which could be used while develop a sorter. The terminal velocity of sapodilla fruit was determined experimentally and empirically by considering the theory of KHAT 2. Experimental measurements were made by dropping the fruit into the water column, while the calculations were empirically considering the parameters of physical properties such as differences in density between fruit and water, volume and shape factor. The results showed that the obtained model was $v_t = 165.370 (\rho_f - \rho_w)^{0.026} V^{0.813} Sh^0 + 0.070$. The model has maximized the value of R^2 , minimizing the RMSE value and reducing the chi-square value which were 0.9046, 0.008 and 7.300E-05, respectively. Volume was the most effective parameter while determining terminal velocity of sapodilla fruit.

Keywords: Sapodilla fruit, density, shape factor, terminal velocity and volume.

Pemodelan Kecepatan Terminal Buah Sapodilla (*Manilkara zapota* (L.) van Royen) Pada di Air

Andasuryani^{1*)}, Renny Eka Putri¹⁾

¹⁾ Agricultural Engineering Dept., Andalas University, Padang, 25163, Indonesia

E-mail: andasuryani@ae.unand.ac.id

Abstrak

Kecepatan terminal adalah salah satu sifat buah hidrodinamik yang signifikan dalam pengembangan peralatan penyortiran. Penelitian ini bertujuan untuk menentukan kecepatan terminal sapodilla yang dapat digunakan saat mengembangkan penyortir. Kecepatan terminal buah sawo ditentukan secara eksperimen dan empiris dengan mempertimbangkan teori KHAT 2. Pengukuran eksperimental dilakukan dengan menjatuhkan buah ke kolom air, sedangkan perhitungan secara empiris mempertimbangkan parameter sifat fisik seperti perbedaan kepadatan antara buah dan

faktor air, volume dan bentuk. Hasil penelitian menunjukkan bahwa model yang diperoleh adalah $vt = 165.370 (\rho f - \rho w) 0,026 V 0,813 Sh0 + 0,070$. Model ini telah memaksimalkan nilai R^2 , meminimalkan nilai RMSE dan mengurangi nilai chi-square yang masing-masing adalah 0,9046, 0,008 dan $7,300E-05$. Volume adalah parameter yang paling efektif saat menentukan kecepatan terminal buah sawo.

INTRODUCTION

Sapodilla (*Manilkara zapota* (L.) van Royen) is a family of Sapotaceae that can produce flower and fruit throughout the year. Many sapodilla fruits are consumed as fresh fruit because its texture of the typical fruit flesh and sweet taste. The sapodilla fruit contains a lot of sugar that is between 12 and 14 percent whereas on 100 g edible parts of the sapodilla, containing water (73.7 g), carbohydrates (21.49 g), protein (0.7 g), fat (1.1 g), calcium (28 mg), phosphorus (27 mg), iron (2 mg) and ascorbic acid (6 mg) (Bose and Mitra, 1990). In addition, various processed products could be produced from sapodilla such as jam, jelly, osmodehydrated and squash slices (Reddy, 1959), sweet sauce, dried fruit (Sawant, 1989), even wine (Gautam and Chundawat, 1998). The sapodilla also contains polyphenols, sap, some types of pigments and secondary metabolites. Existence of these components in the sapodilla fruit lead this fruit could be used as cough medicine, diarrhea, fever, antibiotics, and antimicrobial (Chanda and Nagani, 2010).

The sapodilla fruit is part of the climateric fruit and requires special postharvest handling such as optimal harvest time to maintain fruit quality and yield loss (Yahia and Gutierrez-Orozco, 2011). Sapodilla plants have an unpredictable flowering and fruiting habit that causes difficulty in determining optimal harvest time (Lakshminarayana, 1980). The sapodilla which was harvested at the optimum maturity stage will mature within 5-7 days at room temperature. On the contrary, the sapodilla will have poor quality when ripe if it was harvested before the optimum stage and would have shorter postharvest life if the fruits were harvested slower than the optimum maturity stage (Roy and Joshi, 1997).

Maturity index is needed to determine the timing of sapodilla fruit harvest. The physiological maturity index of sapodilla visually had a soft texture on the skin (Lakshminarayana, 1980) and fruit with smooth surface, bright brown potato color and rounded styler tip (Kute and Shete, 1995). Another maturity index was the presence of green or latex tissue when scratched with fingernails and the fruit will be easily released from the stem without removing latex because the latex content in ripe fruit is reduced to nearly zero (Sulladmath and Reddy, 1990). Total soluble solids were also used as a determinant of maturity of sapodilla fruit (Sundararajan and Rao, 1967). In addition, Abdul-Karim et al., (1987) acknowledged that fruit size (length and width) is a better index of maturity.

Harvesting at different levels of maturity certainly delivers yields of varying quality. This can affect the commercialization of fresh sapodilla fruit in the market or when processed in the food processing industry made from raw sapodilla. One attempt to overcome the above problems is with appropriate postharvest handling such as fruit selection. Chauhan and Singh (2014) acknowledged that external factors such as size, shape, color, defect and external damage, etc. are the basis of fruit gradation. However, consumers always choose fruit of the same size which would be the basis of the sorting of fruit by size. They also explained that proper fruit sorting will result in uniformity in fruit size, reduced packaging and transportation costs and provision of optimum packaging configurations.

Sapodilla sorting is usually done manually. Although humans can do the sorting process, but due to their limitations such as inconsistent or subjective judgments, exhausting and time-consuming, then postharvest equipment is required for the fruit selection process. Various types of sorters and graders have been developed by researchers in accordance with market demand and processing aspects which are designed based on size, shape, weight, color etc., (Londhe et al., 2013). In general, the type of grader developed was a mechanical that usually used conveyor belt, roller and so on. As reported by Patil and Patil (2002); Ukey and Unde (2010) that they had designed, developed and tested the performance of fruit graders of sapodilla type divergent roller based on fruit size.

Hydraulic sorting is one of the alternatives that can be applied to fruit. Designing the hydraulic sorter requires information on the hydrodynamic properties of the fruit. Kheiralipour et al. (2008a) acknowledged that hydrodynamic properties were importance for hydraulic transport, handling and sorting of agricultural products. Terminal velocity is one of the hydrodynamic properties that play an important role in the process of sorting the fruit. Jordan and Clark (2004) and Kheiralipour et al. (2009) explained that for fruit sorting could use terminal velocities in liquids that had a density above or below the target density. They explained that fruits with different terminal velocities would reach different depths after flowing at a fixed distance in a flume and could be separated by a suitable divider. Water could be used as a sorting medium to provides low corrosion benefits and does not require density regulation. In addition, this approach allows full mechanical arrangement of the dividing boundary by adjusting the position of the dividers and requires no change in the fluid density itself.

Terminal velocity was initially seen as fruit shape, size, and density function (Mirzaee et al., 2008). To explain how characteristics of sapodilla terminal velocity in the hydraulic sorting process, mathematical modeling needed to determine whether the terminal velocity has the potential for the sorting process. Several researchers have developed simulation models to evaluate the terminal velocity potential, including terminal velocity modeling for apricot fruits (Mirzaee et al., 2008), Hayward kiwi fruits, Redspar and Delbarstival apples (Kheiralipour et al., 2009) and tomatoes (Taheri-Garavand et al., 2010). However, there is no study of modeling of sapodilla terminal velocity. This study aimed to determine terminal velocity of sapodilla in water column to get information about the potential terminal velocity for sorter purpose.

MATERIALS AND METHODS

Sample Preparation

The material used in this study was sapodilla fruit local varieties of Sumpur, West Sumatra, Indonesia. Once it was harvested, the skin's fruit was cleaned to remove dirt and gum attached. A hundred of sapodilla was divided into two parts, 63 fruits were used to build the model and 37 fruits were used for validation. The sapodilla was brought to laboratory of Food Processing Technology and Agricultural Products, Faculty of Agricultural Technology, Andalas University, Indonesia. The fruits were packaged using polyethylene bags to reduce water loss during transportation.

Measurement and data collection of sapodilla size were conducted immediately once the fruits were delivered in the laboratory. Parameters were fruit diameter which include major, minor and moderate. The diameters were measured by a caliper with 0.1 mm accuracy. These diameters were used to calculate the value of Geometric Mean Diameter (GMD) as seen in equation 1 (Mohsenin, 1986). The value of GMD was used to group the fruits.

$$\text{GMD} = (L \times W \times T)^{\frac{1}{3}} \dots \dots \dots (1)$$

where :

L = Length (cm)
W = Width (cm)
T = Thickness (cm)

Measurement and data collection of terminal velocity were conducted on the next day. Prior to measurement, the sapodilla was stored at a temperature of 17⁰ C. All measurements and data were taken at room temperature.

Experimental Procedure

Determination of terminal velocity by experiment was conducted by preparing a water column, created refers to Taheri-Garavand et al. (2010), made from glass with a height of 1200 mm and a cross section of 350 mm x 350 mm. The water column was filled with water as high as 1100 mm (Kheiralipour et al., 2008a). Water came from rain. The fruit was placed at the top of the column prior to released into the column. Any movement of sapodilla fruit in the water will be recorded by a digital camera (FHD 1080P). Result of the recording was converted into image with 30 fps so that in each image takes time of 0.033 s. This process was conducted by video to frame software. Each fruit was tested with three experiments.

Mathematical modeling of terminal velocity

Theory of KHAT 1 and KHAT 2 showed that variables considered while determining terminal velocity was differences between densities of water and fruit, volume, and shape factor (Kheiralipour et al., 2009). Theory KHAT 2 (equations 2 and 3) is used for modeling of higher sapodilla fruits terminal velocity (NR>1). Values A, b, c, d and E were obtained using Microsoft Excel Solver (Microsoft Office, USA).

$$v_t = K \frac{(\rho_f - \rho_w)^{\left(\frac{1}{2-n}\right)} V^{\left(\frac{n+1}{3(2-n)}\right)}}{S_h^{\left(\frac{1}{2-n}\right)}} \dots \dots \dots (2)$$

$$v_t = A(\rho_f - \rho_w)^b V^c S_h^{-d} + E \dots \dots \dots (3)$$

where: v_t = terminal velocity (m.s⁻¹)
 ρ_f = fruit density (g.cm⁻³)
 ρ_w = water density (g.cm⁻³)
 V = fruit volume (cm³)
 S_h = shape factor
A,b,c, d and E = constant factor

Fruit density and volume were determined using the water displacement method (Mohesenin, 1986). The density was calculated by dividing the fruit mass by the volume of the fruit. The mass of sapodilla fruit was determined using analytical balance with readability 0.001 g (KERN PLJ 360-3M, Germany). The fruit volume was calculated using equation 4, where density of water = 1 g.cm⁻³. Meanwhile, shape factor was calculated using equation 5 (Jordan and Clerk, 2004).

$$\text{Fruit unit volume (cm}^3\text{)} = \frac{\text{Weight of displaced water (g)}}{\text{Density of water (g.cm}^{-3}\text{)}} \dots\dots\dots(4)$$

$$\text{Sh} = \frac{A_p}{V^{2/3}} \dots\dots\dots(5)$$

Sh = Shape factor

Ap = Projected area (cm²)

V = Fruit volume (cm³)

Measurement of the projection area referred to Simonyan et al. (2009). The projected areas of the sapodilla were determined using an overhead projector (Aroni Universal 300). A three-meter vertical screen was used as a projection medium. Lens focusing was done to obtain a sharp image of the grain boundary on the graph paper. Tracking of projection image outline was done on graph paper. To determine the enlargement factor, the millimeter scale was also tracked. The approximate projected area is calculated by summing squares within the trackable boundary. To obtain the area of the projected area, the number of squares was multiplied by the area of the graph. The calculation was divided by the magnifying factor to obtain the projected zone.

Futhermore, projected areas including A_{P1} (the area perpendicular to axial diameter L), A_{P2} (the area perpendicular to axial diameter W) and A_{P3} (the area perpendicular to axial diameter T) of each fruit. The criteria projected area (A_P) was referred to equation 6 (Tarigi et al., 2011):

$$A_P = \frac{A_{P1} + A_{P2} + A_{P3}}{3} \dots\dots\dots(6)$$

This study tested six models. Model 1 was a model that involves all parameters that determine the terminals velocity i.e. difference between densities of fruit and water, volume, and shape factor. Model 2 did not consider parameter difference densities between fruit and water. Model 3 did not consider volume parameter. Model 4 did not consider shape factor parameters. Model 5 did not involve two parameters namely densities difference between fruit and water, and shape factor. Model 6 did involve two parameters of volume and shape factor. The best model was a model that maximizes the coefficient of determination (R^2) value (equation 7), minimizes the root mean square error (RMSE) value (equation 8) and reduces the value of chi-square (χ^2) (equation 9).

$$R^2 = 1 - \frac{\sum_{i=1}^N [v_{t \text{ exp}_i} - v_{t \text{ model}_i}]^2}{\sum_{k=1}^N \left[\frac{\sum_{i=1}^N v_{t \text{ model}_i}}{N} - v_{t \text{ model}_i} \right]^2} \dots\dots\dots(7)$$

$$\text{RMSE} = \left[\frac{1}{N} \sum_{i=1}^N (v_{t \text{ exp}_i} - v_{t \text{ model}_i})^2 \right]^{1/2} \dots\dots\dots(8)$$

$$\chi^2 = \frac{\sum_{i=1}^N (v_{t \text{ exp}_i} - v_{t \text{ model}_i})^2}{N-m} \dots\dots\dots(9)$$

RESULTS AND DISCUSSION

The velocity model of sapodilla fruit with several parameters considered in building the model is shown in Table 1. Model 1 involves all parameters in determining terminal velocity. However, to obtain a good performance, zero value was generated for constant factor of shape factor. Model 2 considered volume and shape factor. Like model 1, this 2nd model resulted a zero value for constant factor of the shape factor. Model 3 considered densities difference between fruit and water, and shape factor, where the value of constant factor of densities difference between fruit and water was zero. Model 4 involved densities difference between fruit and water, and volume. It was seen that performance of model 4 was like model 1. Model 5 only considered volume and resulted similar performance to model 2. Lastly, model 6 only considered densities difference between fruit and water. Similar to model 3, model 6 resulted a value of zero for constant factors of densities difference between fruit and water. It meant that none of the three parameters involved in building the model. This result was incompatible with KHAT 1 and KHAT 2 theories where terminal velocity was proportional to difference densities among fruit and water, volume, and shape factor (Kheiralipour et al., 2009).

Table 1. Comparison of terminal velocity models and statistical results obtained from of sapodilla fruit

Model	A	B	c	D	E	R ²	RMSE	χ^2
1	136.413	0.025	0.789	0.000	0.068	0.9045	0.008	7.3105E-05
2	118.738		0.763	0.000	0.067	0.9008	0.009	7.594E-05
3	0.182	0.000		3.571	0.106	0.2567	0.023	0.001
4	165.370	0.026	0.813		0.070	0.9046	0.008	7.300E-05
5	303.491		0.877		0.078	0.9013	0.009	7.553E-05
6	0.077	0.000			0.077	0.0467	3.17E-32	0.027

This study further explained that model which considering certain parameters produced a good performance (high R², RMSE and small χ^2) which effective in determining the terminal velocity of sapodilla fruit. For example, every model which considered the volume (model 1, 2, 4 and 5) resulted a good performance. However, if the volume was not involved in building the model (models 3 and 6) then the model resulted a poor performance. Thus, it could be concluded that volume was the most effective parameter to determine terminal velocity of sapodilla.

However, other studies found that difference between the fruit and water densities was the most effective parameter. As reported by Taheri-Garavand et al. (2010a) for tomatoes (cv. *Riogrand s*), Taheri-Garavand et al. (2010b) for tomatoes and potatoes, Mirzaee et al. (2008) for Ghavami, Nasiry and Rajabali apricot varieties. It could explain that the sapodilla fruit was the nature of the sapodilla tree which flowering throughout the year. It led that on a tree there were fruits with different developmental levels which different chemical compositions, such as sugar content. The content of sugar in the fruit could be identified based on the density value. As reported by Karnataka (2011) that the increased sugar content in sapodilla fruit, the decreased the density. This was a possibility that caused less effective densities in determining the terminal velocity of sapodilla. On the other hand, volume of fruit was very effective in determining the terminal velocity of sapodilla. The volume of fruit was determined by the size of the fruit, where the larger the size the greater the volume. The size of the sapodilla fruit was a better index of maturity as stated by Abdul-Karim et al., (1987).

The plotting between terminal velocity and volume shows the highest R^2 value of 0.9007 (Fig.2), followed by a shape factor with R^2 value of 0.2331 (Fig.3) and the lowest is the densities difference between fruit and water of R^2 value of 0.1628 (Fig.1). In addition, plotting between terminal velocity and volume shows a fruit size grouping, where the larger the size of the fruit, the greater the volume of fruit and the terminal velocity. The grouping of sapodilla size used in this study was based on GMD values of A, B and C size which were $GMD < 4.92$ cm, $4.92 \text{ cm} \leq GMD < 6.2$ cm and $GMD \geq 6.2$ cm, respectively. The value of the terminal velocity of sizes A, B and C is shown in Fig. 4.

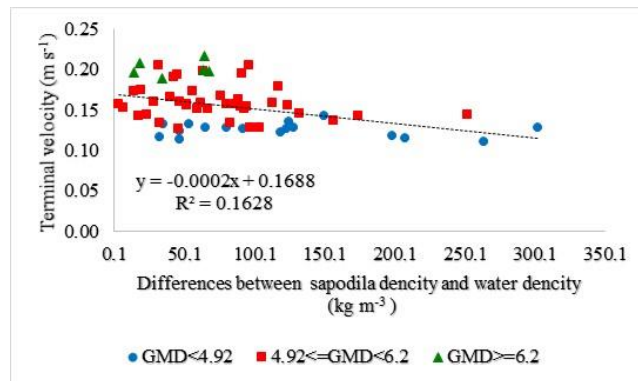


Fig. 1. Plotting between terminal velocity and difference densities between fruit and water of sapodilla fruit

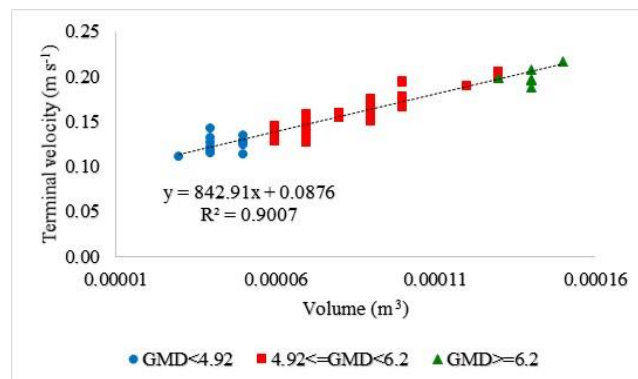


Fig. 2. Plotting between terminal velocity and volume of sapodilla fruit

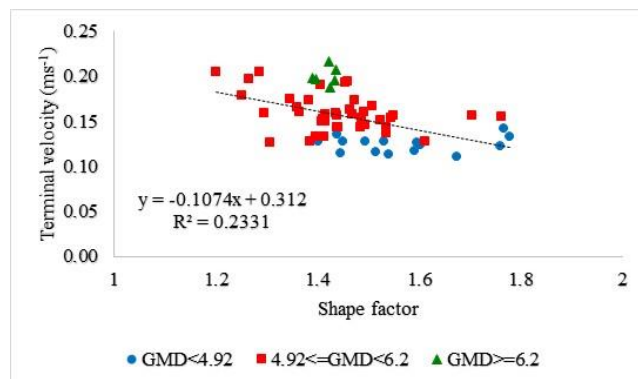


Fig. 3. Plotting between terminal velocity and shape factor of sapodilla fruit

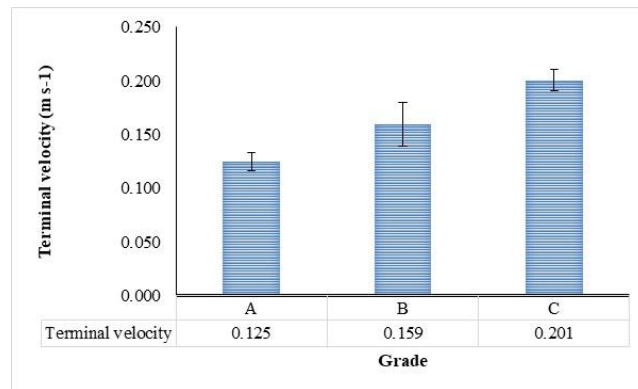


Fig. 4. Terminal velocity based on size of sapodilla fruit

The best model was a model that maximizes the R^2 value, minimizes the RMSE value, and minimizes the value of χ^2 . Model 1 and model 4 produced similar performance. Both models involved several different parameters. Model 1 involved density, volume and shape parameters whereas model 4 considered density and volume parameters. To obtain a good performance, model 1 gave a zero value in the constant factor of shape factor. Therefore, the number of effective parameters for building model 1 was the same as model 4. Model 4 showed a slightly better performance than model 1. Therefore, the best model was model 4 since it had better values of R^2 , RMSE, and χ^2 which were 0.9046, 0.008 and 7.300E-05 respectively.

The mathematical equation of the best model could be seen in equation 10. Furthermore, based on this equation, the terminal velocity could be predicted. Plot of experimental terminal velocity with prediction could be seen in Figure 5. The accuracy of model validation was tested by using new data sets outside the data used to build the model (set calibration). The result indicated that the model built was good with the indicator R^2 validation value of 0.8087. Figure 6 shows the plot between the experimental of terminal velocity and the predictive velocity terminal, both in set calibration and set validation.

$$v_t = 165.370(\rho_w - \rho_f)^{0.026} V^{0.813} S_h^0 + 0.070 \dots \dots \dots (10)$$

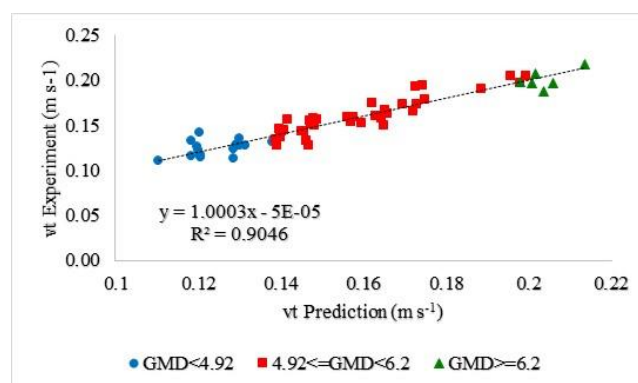


Fig.5. Plotting between experimental and prediction of terminal velocity

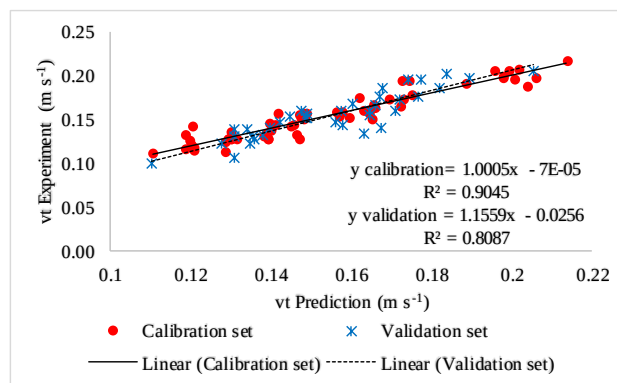


Fig. 6. Plotting between experimental of terminal velocity and terminal velocity prediction on set calibration and validation set.

CONCLUSIONS

This study found that the best model in determining the terminal speed of sapodilla fruit was a function of density and volume. The model showed a high R^2 value of 0.9046, the low RMSE of 0.008 and χ^2 of 7.300E-05. Furthermore, the result showed that volume was the most effective parameter to determine sapodilla fruit terminal velocity. It also could show the grouping of sapodilla based on size and possibility to develop a design of hydraulic sorting equipment.

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