Textural Behavior of Ripening Sapota Fruits

B. Rahardjo[1], **Tranggono**[2] **and J. S. Dethan**[3]

[1]Department of Agricultural Engineering, Gadjah Mada University, Yogyakarta, Indonesia
[2]Department of Food Science and Nutrition, Gadjah Mada University, Yogyakarta, Indonesia
[3]Department of Agricultural Engineering, Arthawacana Christian University, Kupang, Indonesia

ABSTRACT

Physical quality of fruits is commonly determined by their texture. The texture of fruits often depends on its maturity level. Generally the texture of fruits is quantified by their firmness that is defined as the force to attain certain deformation. However fruits can not be considered as simple elastic materials. They are more appropriately considered as non linear viscoelastic objects with three parameters. Accordingly the objectives of the study were to determine the viscoelastic parameters of fruits by impact and to relate those parameters to the sensory evaluations of the maturity of the samples. Samples were sapota fruits stored and ripened at room temperature. The samples were impacted onto hard surface and the impact forces were recorded using a computer. The impact forces were analyzed to determine the viscoelastic parameters. The maturity indices of the samples were determined by sensory evaluation and then compared to the impact parameters. The results indicated that the impact parameters can be related to the maturity index. It seems that the maturity of fruits can be determined by impact.

INTRODUCTION

Physical quality of fruits is commonly evaluated by their physical behavior known as fruit texture. The fruit texture is used to indicate the mouth feels for chewing the fruit tissues. The texture is commonly quantified as the fruit firmness or fruit hardness. Firmness in fruits frequently is defined as a force to attain certain deformation on their surface. Besides using color identification, fruit firmness can be used to indicate the maturity level of fruits. During ripening fruits lose their hardness that make them delicate for mouth feel.

Strength and firmness of fruit tissue depend on its turgidity, size and shape of the tissue cells, the cell bounds and the supporting cells. The parenchyma cells of the tissue are bonded together by a pectin layer constructing strong food tissue. The cell bound depends on the available pectin substances, while the cell liquid and its solution such as starch, sugar, protein, acids, protein and pectin determine the fluid viscosity. During ripening the pectin changes to more soluble forms that make the cells disintegrate and loss their strength. Additionally the cell walls become less thick. The plasmalemma are more permeable that makes the fruit tissue softer. Moreover the chemical compositions of the cell fluids change physiologically. Consequently the changes that occur during ripening make the cell walls less elastic and the cell fluids more viscous (Battisse et. al., 1994, Mazliak, 1987; Shewfel et. al., 1994; Weichmann, 1987; Wills et. al., 1981).

Some research revealed the relationship of the textural behavior of the fruit with the chemical changes during ripening. Shewfel et. al. (1971) reported of the textural changes of peaches during ripening. The peaches tend to soften during ripening. They stated that the softening of the peach tissue is due to the decrease of the pectin concentration. Batisse et. al. (1994) reported that the pectin concentration in cherry decreases during ripening. The decreasing pectin concentration makes the fruit texture get soft during in storage. Gautz and Bhambare (1990) observed the concentration of pectin and the viscoelastic of mango fruits. They found that the elasticity of the cell walls decreases and the viscosity of the fruit fluid increases during storage.

The fruit tissue behaves as an elastic material and a viscous material or known as a viscoelastic material (Mohsenin, 1986; Peleg, 1985; Pitt, 1982; Pitt and Chen, 1983). The viscoelastic objects can be modeled as a parallel structure of an elastic element (spring) and a viscous element (damper). The spring represents the elastic behavior and the damper stands for the viscous behavior. The simple model is to assume that the spring and the damper have linear properties or known as the

Kelvin model. The elastic force and the viscous force will be linearly proportional to the deformation and rate of deformation. The linear model is simple such that its differential equation can be solved analytically (Mohsenin, 1986 and Peleg, 1985). However, lot of research indicated that the viscoelastic spherical object can not be appropriately represented by the linear model. The elastic force and the damping force are not linearly dependent on the deformation and the rate of deformation. Lichtensteiger (1988a and 1998b) and Peleg (1985) indicated that for a spherical object is appropriately represented by non linear model with the elasticity and damping coefficient dependent on the deformation or displacement.

The maturity of fruit manually is determined by pressing the finger tips onto the fruit surface. Based on this pressure feel any one can evaluate the maturity level of the fruit according to his experiences. Therefore the deformation force can be used to indicate the maturity level of fruits. The deformation force or as the firmness of fruits sometimes is evaluated as being the force necessary to attain a given deformation within the products. Several firmness objective measurements were developed to substitute the subjective methods. The common method to determine the firmness of fruits is to measure the failure strength of the tissue. However, the method is considered as a destructive method. Firmness sometimes is determined by the elasticity of the tissue. This elasticity is measured as the necessary force to attain certain deformation or as the Young's modules. The elasticity can be determined by mechanic force (Instron) and by sonic vibration (Finney et. al., 1967). Abbot (1994) compared the evaluation of fruit firmness by using sensory evaluation, sonic vibration and mechanic compression. He revealed that the objective measurement has significant relation with the subjective evaluation (sensory). However, the Magnes-Taylor or the mechanic compression did not reveal the fruit behavior as a viscoelastic object. The force to rupture is affected by its elastic and viscous properties. The fruit firmenss from the sensory perception can be expressed by its elasticity. However, from the view point of fruit quality it will be more appropriate to express the fruit texture based on the viscoelastic properties (Harker and Hallet; 1994; Holt and Schrool, 1977; Peleg, 1985).

The most common method to observe the viscoelastic behavior of sphere is to apply impact. Impact can be of free falling the object onto a hard surface or colliding a hard object to the sphere surface (Fluck and Ahmed, 1973). Some research reported the relationships of the impact behavior of a viscoelastic object with their firmness. Dewilche (1987) developed theory to relate firmness with the viscoelastic parameters. Furthermore Dewilche et al. (1987) used the impact analyses to determine the firmness of peach fruits. They stated that the viscoelastic or impact parameters can be used to determine fruit firmness. Lichtensteiger et. al. (1988b) studied the impact behavior of viscoelastic spheres. They also exposed the impact behavior of tomatoes during ripening. They indicated that the ripening tomatoes affect the impact behavior. Using impact Dethan et. al. (1997) studied the viscoelastic behavior of the ripening sapota fruits. They compared the maturity index with the impact parameters of the sapota fruits. They indicated that the impact parameters obviously related to the maturity index. Rohrbach et. al. (1982) determined the firmness of the blueberries based on the impact behavior. They used the classification of firmness to sort the fruits.

Accordingly the objectives of the study were to determine the viscoelastic parameters of spherical fruits by impact and to relate those parameters to the sensory evaluations of the maturity of the samples during ripening. The levels of the fruit maturity were indicated by their taste and hardness. Mathematical models were developed to estimate the maturity level of the fruits.

MATERIALS AND METHODS

Theory

The simple model of a viscoelastic object is a linear model or known as the Kelvin model. However, Lichtensteiger et. al. (1988a) indicated that the Kelvin model is not appropriate to represent the impact behavior of spherical objects. He revealed that the non linear viscoelastic model is better to represent the impact behavior of spherical objects. Accordingly the deformation force F_1 of the non linear viscoelastic object impacted on flat surface and related to the deformation X and the rate of deformation V is given as follows:

$$Fi = BXV + KX^n \quad (1)$$

As shown on equation (1), the viscoelastic behavior of spherical objects can be indicated by three parameters namely damping coefficient B, consistency K and index of consistency behavior n. The damping coefficient B represents the viscosity of the fluids contained in fruit cells. Commonly the more ripened of the fruits will be the more viscous the cell liquids. The value of K represents the consistency of the fruit cell structure. The value of $KX^{(n-1)}$ represents the elastic behavior of the fruits. This parameter frequently is used to represent the hardness or the elasticity of the fruits. The K value decreases as the fruits become ripened or the fruits become softened. Every viscoelastic object has its own specific parameters that differ from others. The three parameters will distinguish the viscoelastic behavior of spherical fruits. Accordingly the values of the viscoelastic parameters can be related to the maturity level of ripening fruits (Dethan, 1997; Harker and Hallet, 1994; Van Woensel et. al., 1987).

The texture of fruits is quantified by the viscoelastic parameters which change during fruit ripening. Using P to represent the impact parameters, therefore their time dependent can be expressed as the kinetic model of the first order as follows:

$$\frac{dP(t)}{dt} = -kP(t) \tag{2}$$

For the decreasing textural parameters during ripening, the initial condition is $P(t = 0) = Po$ and the boundary condition is $P(t = \infty) = 0$. Therefore the solution of equation (2) is found as the follows:

$$\frac{P(t)}{P_0} = \exp(-kt) \tag{3}$$

For the increasing parameter during ripening the rate of parameter change will be positive but with decreasing value as on equation (2). Combining equation (2) and equation (3) the rate of change for increasing parameter can be shown as follows:

$$\frac{dP(t)}{dt} = C\exp(-kt) \tag{4}$$

The constant C can be modified necessarily to accommodate the boundary conditions required to solve equation (4). The solution of equation (4) is determined with initical condition as $P(t = 0) = P_0$ and with boundary condition as $P_0 < P(t > 0) < P_{max}$. However, P_{max} can not be determined during fruit ripening. Therefore the solution of equation (4) for the increasing parameter is given as the follows:

$$\frac{P(t) - P_0}{P_0} = A[1 - \exp(-kt)] \tag{5}$$

Referring to equation (5) therefore the constant C is found to be equal to kAP_0 Accordingly both equations (3) and (5) can be used to express the textural behavior of fruits during ripening. The consistency K and the elastic behavior index n will behave as equation (4), while the damping coefficient B tends to follow equation (5).

Samples

Samples for the experiment were sapota fruits (*Achraz sapota*) found around the city of Yogyakarta. The weight of each sample was about 0.1 kg. The fruits were selected that close to spheres and were fully mature indicated by the yellowish brown color. After harvest the samples were washed and were stored at room temperature during experiment to let the fruits ripened.

Impact Measurement

The impact was conducted by applying the free fall of the samples on a hard flat surface. The experiment was performed with impact height of 50 mm that caused initial impact velocities of 0.99 mm/ms. The impact force was measured by a dynamic force transducer and recorded by a computer. A computer program was developed to calculated the deformation and velocity of the object during in contact with the flat surface. Data sets containing of impact force, impact velocity and impact deformation were used to estimate the impact/viscoelastic parameters (Rahardjo, 1994).

Parameter Estimation Procedure

A computer program was written based on the parameter tracking method to estimate the viscoelastic parameters. The simulation requires two inputs of impact velocity V and corresponding deformation X, and one output as the impact force F_1. Twenty nine pairs of data were collected from each impact test and then used for the parameter estimation (Rahardjo, 1994).

Sensory Evaluation

The maturity of the samples was evaluated subjectively by five panelists. The evaluation included hardness and taste evaluations. The hardness of the fruits was classified into very hard, hard, less hard, soft and very soft. For comparison the fruit hardness is also determine using cone penetrometer. For the taste evaluation the tastes of the samples were classified into five categories that were bitter, bitter with little sweet, sweet with little bitter, sweet and very sweet. (Bitter is used to describe the taste of unripe sapota fruits.)

Data Analyses

The relationships of the viscoelastic parameters to the storage time were analyzed using linear regression analyses. The consistency K and the index of consistency behavior n were analyzed by applying equation (3). The damping coefficient B was determined using equation (4) and equation (5). The constant of the change rate of k was calculated by equation (4). Accordingly the constant A and initial damping coefficient B_0 were determined using equation (5). The regression analyses were conducted using available programs (QPro, Borland).

RESULTS AND DISCUSSION

The viscoelastic parameters of the sapota fruits change during storage. The elasticity of fruits indicated by the consistency K and index of consistency behavior n tends to decrease during ripening. Figures 1 and 2 show the consistency K and index of consistency behavior n during storage for more than six days. The relationship of the consistency K with the storage time during ripening can be expressed as follows:

$$\frac{K(t)}{K_0} = \exp(-0.59\ t) \qquad (6)$$

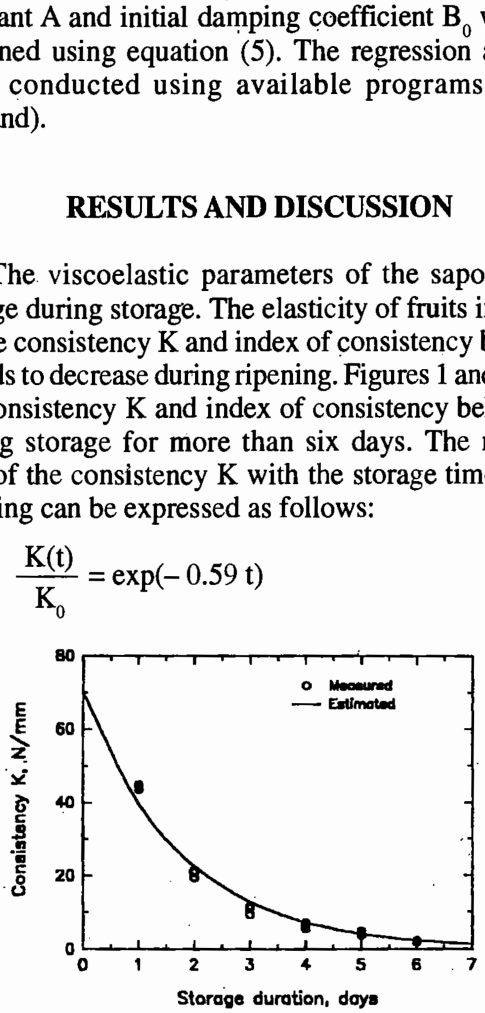

Figure 1. **Consistency K of ripening sapota fruits. The fruits were considered ripe after stored for three days with $K < 12\ N/mm^n$ and were overripe when stored for more than five days with $K < 4\ N/mm^n$**

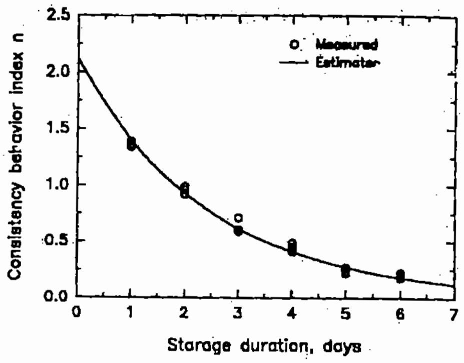

Figure 2. **Index of consistency behavior n of ripening sapota fruits. The fruits were considered ripe after stored for three days with $n < 0.7$ and were overripe when stored for more than five days with $n < 0.3$**

The initial consistency K_0 is found to be 70.19 N/mm^n with $r^2 = 0.986$. This result indicates that the decreasing consistency K can be represented the kinetic equation quite well. Similarly the relationship of the index of consistency behavior n with the storage time can be expressed as follows:

$$\frac{n(t)}{n_0} = \exp(-0.41\ t) \qquad (7)$$

The initial index of consistency behavior n_0 is 2.12. The coefficient regression is $r^2 = 0.867$. Both parameters of consistency K and index n will determine the elastic behavior of the samples that can be related to the fruit firmness. In contrast to the consistency K and the index of consistency behavior n, the damping coefficient B increases during storage time. Figure 3 shows the relation of the damping coefficients of ripening samples with storage elapsed time. The relationship of the damping coefficient B's with the storage time can be expressed as follows:

$$\frac{B(t) - B_0}{B_0} = 108\ [1 - \exp(-0.15\ t)] \qquad (8)$$

The initial damping coefficient B_0 is 0.72 N ms/mm², and with $r^2 = 0.868$. The damping coefficient B can be expressed as a linear relationship with storage time quite well. However, linear relationship is not appropriate to represent a time dependent curve with a maximum value. Although the maximum value of the damping coefficient

B was not observed, the model will have a relatively constant value at a sufficiently large t. The maximum value of the damping coefficient was not measured since the fruits were already overripe and were very soft at about six days storage time.

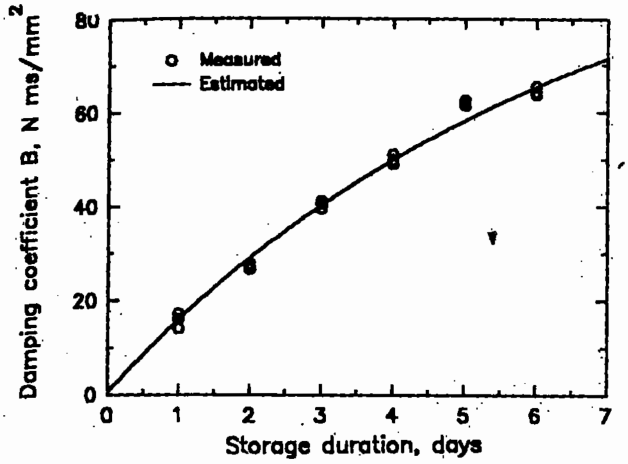

Figure 3. **Damping coefficient B of ripening sapota fruits. The fruits were considered ripe after stored for three days with B > 40 N ms/mm² and were overripe when when stored for more than five days with B > N ms/mm²**

The results indicated that the viscoelastic parameters can be represented with the first order kinetic equation quite well. The maturity of the fruit occured at about three days after harvested. The values of the consistency, the index of consistency behavior and the damping coefficient were about 12 N/mm^n, 0.7, and 40 N ms/mm^2 respectively. Table 1 shows the sensory evaluation of the sapota fruits during ripening. The sapota fruits were suitable for consumption after three days or ripening. Accordingly after for about five days in storage, the fruits can be considered overripe. Most fruits were very sweet and with little bit sour taste. At five day storage time the values of the consistency, the index of consistency behavior and the damping coefficient respectively were 4 N/mm^2, 0.3 and 55 N ms/mm^2. For comparison to hardness determined by cone index, the fruits were considered mature when the rupture pressure was less than 1.78 kg/cm^2. Similarly the fruits were overripe when the rupture occured at 1.17 kg/cm^2. It seems that fruit maturity can be determined based on the viscoelastic parameters. Using equations (6), (7) and (8) the maturity of the fruits during in storage can be estimated. Based on this information any equipment that can determine those viscoelastic parameters can be used to evaluate the level of fruit maturity during storage. Impact as one of the available methods to determine the viscoelastic parameters likely can be developed to sort fruits based their levels of maturity.

Table 1. **Change of the hardness and sensory evaluation of sapota fruits during storage at room temperature (28°C)**

Storages days	Hardness CI kg/cm²	Taste evaluation	Hardness, sensory evaluation
0	3.38	Bitter	Very hard
1	2.87	Bitter	Very hard
2	2.08	Bitter with little sweet	Hard
3	1.78	Sweet with little bitter	Less hard
4	1.65	Sweet	Less hard
5	1.17	Sweet	Soft
6	0.93	Very sweet	Soft
7	< 0.6	Very sweet and sour	Very soft

The evaluation of fruit quality related to the viscosity of the fruit liquid has not understood quite well yet. However, the viscoelastic parameters of the fruits can be used as the parameters in designing the fruit handling system. Several reports showed the relationship of the fruit bruising with the viscoelastic parameters. The damper of the viscoelastic object represents an element that absorbs energy and converts mechanical energy to heat. The absorbed energy significantly determines the volume of fruit bruising. Moreover those parameters can be used to determine the required package cushioning. Higher the consistency will be less necessarily required soft cushioning. Furthermore, the constant rate of charge k of the parameter will be affected by the storage condition. Decreasing the storage temperatures will lessen the ripening rate or the value of k will decrease. The constant k can be related to storage temperature using Arrhenius equation. Similarly the change of concentrations of the oxygen and the carbon dioxide in the storage room will determine the ripening rate. Theoretically the storage conditions can be related to the ripening rate. Therefore if the value of the constant of change rate of k can be determined, the maturity of the fruits can be estimated during storage. Those relationships will be usable storage design and package design for fruits.

CONCLUSIONS

Textural behavior of the ripening fruits can be represented by the viscoelastic parameters such as consistency, index of consistency behavior and damping coefficient. Those viscoelastic parameters can be related quite well to the storage time based on the kinetic equations. The consistency and the index consistency behavior tend to decrease during ripening. However, the damping coefficient increases during storage. The viscoelastic parameters likely can be used to indicate the maturity level. However, the values of the viscoelastic parameters for maturity levels will depend on the characteristic of fruits. Further studies on the relationship of maturity index and viscoelastic behavior are necessary. By providing a rapid method to determine the viscoelastic parameters, the results will be useful for developing fruit handling and sorting systems.

List of Symbols

A = constant
B = damping coefficient, N ms/mm^2
C = any constant number
k = constant rate of change, 1/day
K = consistency, N/mm^n
n = index of consistency behavior
P = representative of the viscoelastic parameters
t = time, day, s or ms

Subscript

0 = initial

REFERENCES

Abbott, J. A. 1994. Firmness Measurement of Freshly Harvested "Delicious" Apples by Sensory Sonic Transmission, Magnes-Taylor, and Compression. J. Amer. Soc. Hort. Sci. 119(3): 510 – 515.

Dethan, J. S. 1997. The Impact Behavior of Spherical Fruits during Ripening. Thesis (Unpublished). Agricultural Engineering Department. Gadjah Mada University. Yogyakarta.

Dewilche, M. J. 1987. Theory of fruit firmness sorting by impact forces. Trans. of the ASAE 30: 1160 – 1166, 1171.

Dewilche, M. J. T. McDonald, and S. V. Bowers, 1987. Determination of peach firmness by analysis of impact forces. Trans of the ASAE 30(1): 249 – 254.

Finney, E. E. Jr., I. Ben-Gera, and D. R. Massie. 1967. An objective evaluation of changes in firmness of ripening bananas using a sonic technique. J. of Food Sci. 32: 642 – 646.

Fluck, R. C and E. M. Ahmed. 1973. Impact testing of fruits and vegetables. Trans. of the ASAE. 19(1): 185 – 191.

Gauttz, L. D. and D. N. Bhambare,1990. Relation between Viscoelastic Properties and Maturity of Mangoes. ASAE Paper No. 90-6043.

Harker, F. R. and I. C. Hallett. 1994. Physiological and Mechanical Properties of Kiwifruit Tissue associated with Texture Change during Cool Storage. J. Amer. Soc. Hort. Sci. 119(5): 987 – 993.

Holt, J. E. and D. Schrool. 1977. Bruising and energy dissipation in apples. J. of Texture Studies (7): 421 – 432.

Lichtensteiger, M. J., R. G. Holmes, M. Y. Hamdy and J. L. Blaisdell, 1988a. Evaluation of Kelvin Model Coefficients for viscoelastic spheres. Trans. of the ASAE 31(2): 288 – 292.

Lichtensteiger, M. J., R. G. Holmes, M. Y. Hamdy and J. L. Blaisdell, 1988b. Impact parameters of spherical viscoelastic objects and tomatoes. Trans. of the ASAE 31(2): 595 – 602.

Mazliak, P. 1987. Membrane and Consequences for the Postharvest Period. In "Postharvest Physiology of Vegetables" (Editor. J. Weichmann), Marcel Dekker. New York.

Noble, R. 1985. The relationship between impact and internal bruishing in potato tubers. J. Agric. Engng. Res. 32: 111 – 121.

Pitt, R. E. 1982. Models for the Rheology and Statistical Strength of Uniformly Stressed Vegetative Tissue. Trans. of the ASAE 25(6): 1776 – 1784.

Pitt, R. E. and H. L. Chen, 1983. Time-Dependent Aspects of the Strength and Rheology of Vegetative Tissue. Trans. of the ASAE 26(5): 1275 – 1280.

Rahardjo, B. 1994. Simulation to Estimate the Parameters of Non Linear Viscoelastic Spherical Model During Impact Using Parameter Tracking Method. Proceeding of The International Agricultural Engineering Conference, Bangkok, 6 – 9 December 1994.

Rohrbach, R. P., J. E. Franke, and D. H. Willits, 1982. A firmness sorting criterion for blueberries. Trans. of the ASAE 25(2): 261 – 265.

Weichmann, J. 1987. Postharvest Physiology of Vegetables. Marcel Dekker Inc. New York.

Wills, R. B. H., T. H. Lee, D. Graham, W. B. McGlasson and E. G. Hall. 1980. Postharvest: An Introduction to the Physiology and Handling of Fruits and Vegetables. The AVI Publishing Company Inc. Westport.

Van Buren, J. P. 1992. Function of pectin in plant tissue structure and firmness. In "The Chemistry and Technology of Pectin", R. G. Walls (editor). Academic Press, Inc., New York.

Van Woensel, G. A., Wouters and J. De Baerdemaeker. 1987. Relation between mechanical properties of apple fruit and sensory quality. J. of Food Proc. Eng. 9(1): 173–189.