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Elasticity of Malaysian Papaya as a design criterion for prevention of damage during transportation

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RINGKASAN

*Kerosakan ke atas buah-buahan semasa di dalam pengangkutan boleh memberi kesan di dalam menurunkan mutu dan harga buah-buahan tersebut. Masalah ini boleh dikaji dari konteks teori getaran. Berdasarkan teori ini, ada kemungkinan untuk kita mengurangkan kerosakan tersebut dengan memanipulasikan frekuensi asli bekas yang digunakan untuk buah-buahan tersebut. Untuk mendapatkan frekuensi asli ini, kekenyalan bagi buah tersebut perlu diketahui. Artikel ini melaporkan hasil ujian mengenai perkara di atas untuk papaya Malaysia (*Carica Papaya, *var. Serdang). Untuk mendapatkan nilai kekenyalan bagi buah tersebut, suatu ujian yang dipanggil 'ujian plat' telah digunakan. Hasil dari ujian ini akan digunakan untuk menentukan frekuensi asli buah tersebut. Dengan mengetahui nilai frekuensi maka akan dapatlah kita merekabentuk bekas yang sesuai dan seterusnya mengelakkan getaran resonans semasa di dalam pengangkutan. Kekenyalan buah tersebut juga boleh digunakan untuk menentukan peringkat bilamana ianya mudah mendapat kerosakan. Untuk buah papaya yang diuji terdapat kemerosotan yang besar di dalam nilai kekenyalannya apabila buah tersebut beransur matang dan ini menunjukkan yang rintangannya kepada kerosakan telah merosot dengan pesatnya.*

SUMMARY

*Damage to fruits for processing and fresh consumption during transportation can be quite significant. This problem can be studied from the context of vibration theory. Based on this theory, it is possible to reduce the damage by manipulating the natural frequency of the container of fruits. To compute this natural frequency, the elasticity of the fruit has to be determined. This article reports the results of a study carried out on the subject for Malaysia papaya (*Carica Papaya, *var. Serdang). The plate test was used to determine the elasticity. Results from the test were used for computing the natural frequency of the fruit. By knowing the frequency, it is possible to avoid resonance vibration during transportation by proper design of container. The elasticity also serves as an indication of the stage at which the fruit is more susceptable to damage. In the case of the Malaysian papaya, there is a substantial drop in elasticity as the fruit matures, indicating that the resistance to bruising and damage is lowered considerably.*

INTRODUCTION

The fruit producing areas in Malaysia are mostly located in villages scattered throughout the country. Before the fruits reach the market, they have to pass through a chain of people. Thus, they are handled and transported for quite a distance between the production point and the retailing point. Transportation is by land, mostly on lorries. Damage to these fruits during the transportation process causes a reduction in value of these fruits. One of the common Malaysian fruit which is subjected to these conditions is papaya *(Carica Papaya,* var. Serdang). The cause of the damage is stated to be fatigue due to repeated forces of vibration on the fruit resulting in cell rupture beneath the skin. This type of damage is commonly referred to as roller bruising.

VIBRATION AND FRUIT DAMAGE

Investigations into the problem of fruit damage during transportation have been carried out by various researchers (Guillou, 1963; O.Brien. *et al.* 1963a; 1965; Murata, 1972). Their studies have revealed that vibration damage occurs in the top layers of fruits within the containers. The extent of such bruising is related directly to the magnitude of vibration accelerations and to the frequency of their occurence in these layers.

The magnitude of vibration acceleration in the upper layers of fruits depends on several interrelated factors. One of them is the vibrating characteristic of the fruit species. Each fruit species has its own vibrating characteristic when placed in a container. This vibrating characteristic can be represented by the parameter which is widely used in vibration theory, namely the natural frequency. This natural frequency can then be related to the vibration characteristic of the transport vehicle. The natural frequency of fruits in a container can be modelled by the equation which describes the vibration of an elastic body with a node at one end (O'Brien *et al.* 1963b; Thomson, 1972). The equation can be represented as follows.

$$f_n = \frac{1}{4\lambda}\left(\frac{Eg}{\rho}\right)^{1/2}$$

where

f_n – natural frequency of the fruits, cps.

E – elasticity of the fruits (Nt/m^2).

g – acceleration due to gravity ($9.81 m/sec^2$),

ρ – density of fruit in the container (Nt/m^3).

λ – depth of the column of fruit (meters).

Computations using the above equation were found to correspond well with those of fruits in bins vibrating at resonance on a laboratory vibrator under simulated transport conditions (O'Brien *et. al.* 1963a).

ELASTICITY OF FRUIT

As can be seen from the above equation for natural frequency, elasticity of the fruit (E) is one of the variables involved. Elasticity of the fruit is not only used to determine the natural frequency in fruit damage study but it also gives an indication of the susceptability of the fruit to damage during transportation.

Elasticity is the capacity of a material for taking elastic or recoverable deformation. It is one of the mechanical properties of fruit which is important and necessary in studying the handling and processing of this agricultural product. Mechanical properties of agricultural products are most conveniently measured with the force-deformation approach which is discussed in details by Mohsenin (1970).

Three methods have been used to obtain such force-deformation characteristic, namely:

a) Plate test – which is the compression of a spherical body by a large flat plate.

b) Plunger test – which is the compression of the product by a small flat cylindrical die.

c) Sample test – which is the compression of a small sample of product cut to uniform size.

Various computation procedures have been developed to determine the elasticity of fruits based on the above mentioned methods. Fridley *et al.* (1968) successfully applied the method based on the plate test. The computation in this procedure is based on equations developed by Hertz for the contact stresses involved in the compression of two elastic isotropic bodies (Timoshenko and Goodier, 1951).

Morrow and Mohsenin (1966) discussed the computation required to compute the elasticity based on the plunger test. It is based on equations for the case of rigid circular die pressed against the plain boundary of a semi-infinite elastic body. Application of this equation to agricultural products assumes that the diameter of the die is very small compared with the size of the product; and the method of support is such that no significant compression of the flesh occurs in the region of contact with the support. It has been shown that this equation applies to fruits whose dimensions exceed 15 times the radius of the die. For some fruits it is possible to obtain a cyclindrical core of constant cross-sectional area. The elasticity of such fruits, such as apples (Mohsenin, *et al.* 1963) and potatoes (Finney and Hall, 1967), can then be obtained by a simple compression test.

The Plate test was found to be preferable for obtaining data on elastic properties of fruits for various reasons. Fristly, results obtained from the plate test compare more favourably with those predicted from theory. Secondly, the plate test is more representative of the type of load application found in practice. Thirdly, test procedure is simpler to perform.

ELASTICITY OF MALAYSIAN PAPAYA

In the study to determine the elasticity of Malaysian papaya, the plate test was used.

The test equipment used is as shown in Figure 1. The calculation of elasticity is based on the following assumptions.

a) The fruit is spherical in shape.

b) Very small expansion in the horizontal plane occurred with compression in the vertical plane.

c) Each side of the fruit in contact with the flat plates has an equal deflection.

Under the above mentioned conditions, the elasticity can be determined as follows, based on the configuration as shown in Figure 2. The compression force F can be represented by the following.

$$F = \int_A \sigma \, dA$$

where $\sigma = \epsilon E$

in which,

ϵ – compressive strain

E – modulus of elasticity

σ – compressive stress

A – area of contact

The compressive strain, $\epsilon = \dfrac{\text{initial size} - \text{final size}}{\text{initial size}}$

It can be represented by the following expression during the compression test.

$$\epsilon = \frac{(R^2 - r^2)^{1/2} - (R - \delta)}{(R^2 - r^2)^{1/2}}$$

Since $dA = 2\pi r dr$, where r varies from 0 to r_m, the modulus of elasticity E, can be expressed as follows.

$$E = \frac{F}{\int_0^{r_m} \frac{\{(R^2 - r^2)^{1/2} - (R - \delta)\} 2\pi r dr}{(R^2 - r^2)^{1/2}}}$$

The value of r_m can be computed from the following expression.

$$r_m = \{ R^2 - (R - \delta)^2 \}^{1/2}$$

Substituting this in the expression for E and evaluating the integral, resulted in the following equation

$$E = \frac{F}{\pi \delta^2}$$

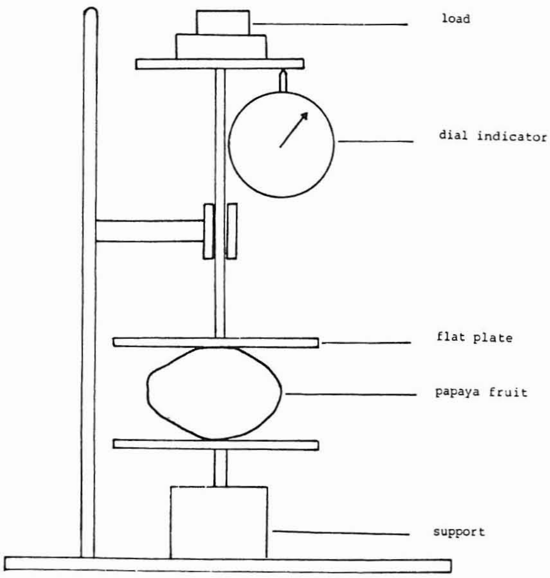

Fig. 1. Test Equipment Used in Compression Test.

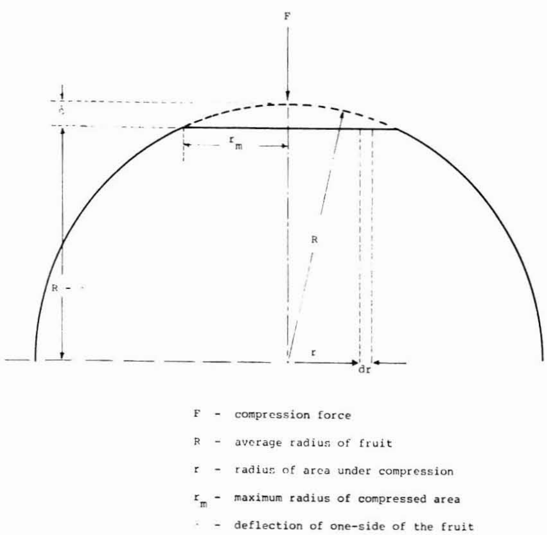

Fig. 2. Diagram of initial and final configuration of fruit during compression test.

RESULTS OF ELASTICITY DETERMINATION

Based on the above procedure, the elasticity of the local papaya was determined at various stages of maturity. The stage of maturity is defined, on the suggestion of Hundtoft and Alacamine (1971), by colour and softness, namely 'mature' when it is mature green to $\frac{1}{8}$ yellow; 'intermediate' when it is $\frac{1}{8}$ yellow to ¼ yellow; 'ripe' when it is ¼ yellow to full yellow; and 'over-ripe' when it is full yellow to very soft structure. The results are shown in Tables 1, 2, 3 and 4 for 'mature', 'intermediate', 'ripe', and 'over-ripe' stages of maturity, respectively. The results indicate that the elasticity of papaya varies substantially with the stage of maturity. The mean modulus of elasticity for 'mature' fruits is 10.80 x 10^5 Nt/m^2, whereas that for 'over-ripe' is 3.01 x 10^5 Nt/m^2.

Elasticity as Design Parameter for Container

The modulus of elasticity values serves two functions in the study of fruit damage during transportation. Firstly, it will be used in the determination of the natural frequency of the fruits in the container via the equation which was described previously. During transportation the fruits in the container will be exposed to an excitation force from the transporting vehicle. This excitation force has a specific frequency range. If the frequency of this excitation force coincides with the natural frequency of the container, a condition of resonance is encountered, and dangerously large oscillations may result. The failure of even major structures, such as bridges, buildings, and airplane wings have been credited to resonance vibration (Crandall and Mark, 1963; Thomson, 1972). Thus, in transporting the fruits, this situation should be avoided.

TABLE 1

Elasticity of Malaysian Papaya at 'Mature' Stage

Force Applied F (kgm)	Average Radius R (cm)	No. of Tests	Mean Modulus of Elasticity (10^5 Nt/m^2)	Standard Deviation
4.24	8.18	8	11.07	1.22
4.24	7.98	10	10.94	0.83
3.25	7.98	10	10.82	1.09
4.24	9.86	9	10.75	1.29
3.25	7.92	10	10.46	1.84

Overall Mean Modulus of Elasticity (10^5 Nt/m^2) = 10.80
Standard Deviation = 1.26

TABLE 2

Elasticity of Malaysian Papaya at 'Intermediate' Stage of Maturity

Force Applied F (kgm)	Average Radius R (cm)	No. of Tests	Mean Modulus of Elasticity (10^5 Nt/m^2)	Standard Deviation
4.24	9.86	9	8.82	0.49
4.24	8.18	8	8.78	0.78
4.24	9.25	8	7.96	1.26
4.24	8.79	10	7.90	0.64

Overall Mean Modulus of Elasticity (10^5 Nt/m^2) = 8.35
Standard Deviation = 0.90

Resonance vibration can be avoided by making sure that the natural frequency of the container with the fruits is out of the range of that of the transport vehicle. This can be achieved by adjusting the natural frequency of the container (Zohadie, 1980).

Susceptability to Damage

The second function which the modulus of elasticity plays in the study is to indicate the stage at which the fruit is more susceptable to damage. As can be seen from the values in Tables 1, 2, 3 and 4, there is a considerable drop in modulus of elascity as the papaya fruit matures. In fact, there is more than three-fold reduction from the 'mature' to the 'over-ripe' stage. Since elasticity is the capacity of the material for taking elastic or recoverable deformation, this considerable drop in elasticity as the fruit matures indicates that the resistance to bruising and damage is lowered considerably as the fruit matures. Thus, it is very critical that the transportation and handling of the fruit be carried out before this drop in elasticity occurs, in order to eliminate bruishing and damage.

With the low modulus of elasticity at the 'ripe' and 'over-ripe' stages, the chance of failure due to yielding, roller bruising and internal damage is high. The bruising is caused by shearing, as the fruits come in contact with each other during handling. In the course of the study, it was also

TABLE 3

Elasticity of Malaysian Papaya at 'Ripe' Stage of Maturity

Force Applied F (kgm)	Average Radius R (cm)	No. of Tests	Mean Modulus of Elasticity (10^5 Nt/m^2)	Standard Deviation
4.24	8.13	10	6.77	2.14
2.25	7.39	10	6.59	0.77
2.25	7.85	10	6.35	0.75
3.25	7.92	10	6.13	0.73
2.25	7.20	11	6.12	1.13
2.25	9.75	9	6.10	0.77
4.24	7.47	10	5.68	0.81

Overall Mean Modulus of Elasticity (10^5 NT/m^2) = 6.25
Standard Deviation = 1.13

TABLE 4

Elasticity of Malaysian Papaya at 'Over-ripe' Stage of Maturity

Force Applied F (kgm)	Average Radius R (cm)	No. of Tests	Mean Modulus of Elasticity (10^5 Nt/m^2)	Standard Deviation
4.24	8.18	10	3.88	0.34
4.24	9.25	9	3.59	0.56
2.25	7.39	10	3.16	0.18
4.25	9.86	9	2.71	0.29
1.24	7.21	10	1.76	0.13

Overall Mean Modulus of Elasticity (10^5 Nt/m^2) = 3.01
Standard Deviation = 0.82

observed that internal damage on the papaya fruit usually occurs first in narrow bands separating the different flesh texture (at both the top and bottom loading surface). The initial damage first occurs as a watery spot barely discernable to the eye. As the damage increases, the spot tends to elongate and increase in size.

CONCLUSION

The modulus of elasticity is a property which is useful as a design criterion in the study of fruit damage during transportation. It can be determined experimentally as was carried out on Malaysian papaya in this study. Besides being used as a design criterion, it also indicates the stage at which the fruit is more susceptable to damage during handling and transportation. In the case of the Malaysian papaya, there is a considerable drop in the modulus of elasticity as the fruit matures. This indicates that the resistance to bruising and damage is lowered considerably as the fruit matures. Thus, it is very critical that the transportation and handling of the fruit be done before this drop in elasticity occurs in order to eliminate bruising and damage.

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