POLISH JOURNAL OF FOOD AND NUTRITION SCIENCES

www.pan.olsztyn.pl/journal/
e-mail: joan@pan.olsztyn.pl

Pol. J. Food Nutr. Sci.
2007, Vol. 57, No. 2(A), pp. 165-167

RELATION BETWEEN MASS AND DROP HEIGHT AT IMPACT CAUSING THE BRUISING OF APPLE

Zbigniew Stropek, Krzysztof Gołacki

Department of Machine Theory and Automatic Control, University of Agriculture in Lublin

Key words: apple, mass, drop height, impact, bruising

The aim of the studies was to establish a relationship between apple mass, impact initial velocity and energy level causing damage of apple flesh tissue. The apples were dropped on a flat, rigid surface at different combinations of fruit mass and drop height. Then the apples were stored at a room temperature for 5 days, after which they were classified as bruised and unbruised. The analysis was also carried out, using nonlinear regression, in order to find the function which would determine the most accurately the limit between the bruised and unbruised apples.

INTRODUCTION

Modelling plant material behaviour under different kinds of loading is still the subject of interest of many investigators [Aviara *et al*., 2007; Gołacki & Rowiński, 2006; Blahovec, 2001; Puchalski & Brusewitz, 2000]. The previous studies aimed at determining the impact influence on fruit and vegetable estimated damage on the basis of bruise volume, bruise surface area or bruise diameter. In addition, it confirmed the correlation between bruise diameter and maximum value of impact force and bruise volume and impact energy. Several researchers showed a linear relationship between bruise volume and impact energy for apples [Chen & Sun, 1981; Pang *et al*., 1992], moreover, bruise size differed among varieties and it stated large scatter of bruise size, occurring at constant impact energy value. Linear correlation between bruise volume and absorbed energy during impact was obtained by Hung & Prussia for peaches [1988] as well as by Brusewitz & Bartsch for apples [1989], although Holt & Schoorl [1984] did not find any statistical relationships for these quantities in the case of apples.

Appearance of bruise in fruit takes place when the load or the strain exceeds the elastic limit. Thereby, it can determine the limit at which acceptable load, strain or impact energy levels do not cause damage to fruit flesh tissue. In most of the carried out experiments the change of impact energy was achieved by the change of impact velocity. It has its justification, in the case when fruit mass is much lower in comparison with the element mass, which a fruit hits. Such a simplification cannot be used in the case of fruit against fruit impact, where apart from impact velocity, mass has also a significant meaning.

The aim of the studies was to carry out measurements on several apple varieties at various combinations of fruit mass and drop height to determine the relationship between body mass, its velocity and deformation energy.

THEORETICAL BACKGROUND

The central impact theory of two masses was used to describe the impact between two bodies. At the end of the first phase of the central impact, the kinetic energy of both masses changes partially into the common kinetic energy of both masses as well as transforms partially into deformation energy. In the case when one of the bodies moving with velocity v_1 strikes on the other being in the rest, energy balance is expressed by formula:

$$\frac{m_1 \cdot v_1^2}{2} = \frac{(m_1 + m_2) \cdot u^2}{2} + E_{def} \tag{1}$$

where: m_1 – the mass of the moving body, m_2 – the mass of the fixed body, v_1 – the velocity of the moving body just before the impact, u – the common velocity of both bodies at the end of the first phase of the impact, E_{def} – the deformation energy.

Using the principle of conservation of momentum at the end of the first phase of central collision of both bodies we receive the relationship:

$$m_1 \cdot v_1 = (m_1 + m_2) \cdot u \tag{2}$$

Assuming that E_{def} is the maximum impact energy, which does not still cause the damage of apple flesh, then v_{1max} is maximum acceptable impact velocity respectively, with which bruise fruit still does not occur.

Calculating from the equation (2) the velocity value u and putting it to the equation (1) we determine the velocity value v_{1max}:

Author's address for correspondence: Zbigniew Stropek, Department of Machine Theory and Automatic Control, University of Agriculture in Lublin, Doświadczalna 50A, 20-280 Lublin, Poland; tel.: (48 81) 461 00 61 ext. 212; fax: (48 81) 461 06 05; e-mail: zbigniew.stropek@ar.lublin.pl

$$v_{1max} = \left(\frac{2E_{def} \left(m_1 + m_2 \right)}{m_1 m_2} \right)^{\frac{1}{2}} \quad (3)$$

The carried out impact tests consisted in apple drop on a rigid, flat surface whose mass was significantly larger than the apple mass. Hence, it can be assumed that the mass m_2 approaches infinity.

Hence the equation (3) will change its form into:

$$v_{1max} = \left(\frac{2E_{def}}{m_1} \right)^{\frac{1}{2}} \quad (4)$$

Deformation energy is the sum of the energy absorbed by both bodies at the end of the first impact phase. Taking into consideration the fact that the steel plate is much more rigid in relation to the apple, it was assumed that only the fruit is deformed, so the total deformation energy refers only to the apple.

MATERIAL AND METHOD

The object of studies were Pinowa, Royal Gala and Florina apples varieties. The measurements were carried out in October and November of 2006. The research material after harvest was in a cold storage and next one day before the experiment, it was carried into a room of 20°C temperature. The impact test was carried out on a measurement stand, acting on the pendulum rule, in which an impact element was an apple dropped on a titanic plate attached to a rigid, steel plate. The measurement stand was also fitted out with a scale with marked quantity corresponding to specific values of free fall height. The apple was placed on a specific drop height and held by a suction pump. The fruit was released through switching off the pump.

In order to diversify fruit mass for experiments whole apples of masses from 80 g to 190 g were selected. Different impact velocities were reached through apple drop at 20, 30, 40, 50 and 60 mm height. In previous experiments the mass ranges for specified drop height of apples in close to bruise threshold were estimated. It allowed to limit the number of samples for each drop height. Five apples were tested for each variety and drop height, moreover masses of the next fruit differed from each other by about 10 g. Before the experiment each apple was numbered and the apple area of the expected bruise was marked. After the impact, the apples were stored at a room temperature and after 5 days they were classified as being bruised and unbruised. The fruit was considered as bruised when brown colour of flesh tissue appeared. To find any changes of colour, the apples were cut in a perpendicular direction to the impact surface in the previously marked area of expected bruise.

RESULTS AND DISCUSSION

Figure 1 depicts the relationship between apple mass and drop height for bruised and unbruised fruit.

In addition, regression analysis by means of different functions was carried out with the aim to show the limit be-

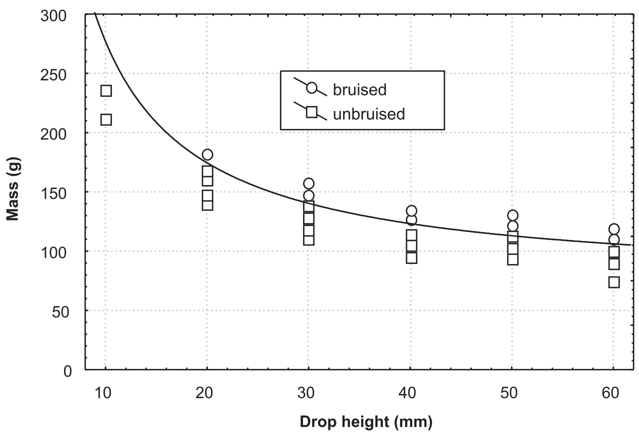

FIGURE 1. The relationship between apple mass and drop height for variety of Florina apple.

tween bruised and unbruised apples and the coefficient of determination for each curve was determined. To find the limiting value, two values were taken for a given drop height. The first value being the least apple mass which was damaged. The other one was the largest unbruised apple mass located directly below the first one.

Four functions (linear, hyperbolic, power and exponential) were compared using nonlinear estimation unit of Statistica software (Table 1). It turned out that a hyperbola for Florina variety as well as a power function for Royal Gala and Pinowa varieties were the best fitting functions. For both last varieties the fitting degree was almost the same for hyperbolic and power functions.

Hyperbolic function has a form of:

$$m = A + \frac{B}{h} \quad (5)$$

where: m is mass, h is drop height, A and B are parameters.

Multiplying both sides of the equation (5) by gh we receive energy balance:

$$mgh = Agh + Bg \quad (6)$$

where g is gravitational acceleration.

The left side of the equation (6) determines limiting energy value, which still does not cause apple damage.

$$E_{max} = Agh + Bg \quad (7)$$

TABLE 1. The values of determination coefficient for the tested functions for three apple varieties.

Function	Variety		
	Folorina	Royal Gala	Pinowa
m= A+B*h	0.9274	0.8592	0.8845
m= A+B/h	0.9714	0.9171	0.9563
m= AB^h	0.9462	0.8835	0.922
m= Ah^B	0.9693	0.9192	0.9569

TABLE 2. Values of parameters of a hyperbolic function and coefficient of determination for three apple varieties.

Variety	A (kg)	B (kg·m)	R^2
Florina	72	2050	0.9714
Royal Gala	87	1591	0.9171
Pinowa	62	2126	0.9563

Impact velocity v_1 can be calculated from the comparison of potential energy and kinetic energy for free fall and it is expressed by a formula:

$$v_1 = (2gh)^{\frac{1}{2}} \tag{8}$$

Hence, the equation (8) will be transformed into the form:

$$E_{max} = A\frac{v_1^2}{2} + Bg \tag{9}$$

The acceptable impact velocity, which still does not cause damage of apple flesh can be determined by the combination of the formulas (4) and (9):

$$v_1 = \left(\frac{2Bg}{m_1 - A}\right)^{\frac{1}{2}} \tag{10}$$

Determined in this case values of *A* and *B* parameters (Table 2) are justified only in the conditions which are similar to those applied during the experiment, thus in the case when an apple struck the rigid, flat plate. Other conditions (two apples collision or an apple impact against a flat surface of another stiffness – padding materials) would result in obtaining new values of *A* and *B* parameters.

CONCLUSIONS

1. Hyperbolic function among all tested is the best fitted curve describing the relationship between apple mass and drop height, which cause bruising at impact.
2. Maximum value of impact energy changes at different combinations of apple mass and drop height, which means that these quantities are independent from each other and have different influence on the outset of damage occurrence in apple flesh.

REFERENCES

1. Aviara N.A., Shittu S.K., Haque M.A., Physical properties of guna fruits relevant in bulk handling and mechanical processing. Int. Agrophysics, 2007, 21, 7-16.
2. Blahovec J., Improved rate controlled model for stress relaxation in vegetable tissue. Int. Agrophysics, 2001, 15, 73-78.
3. Brusewitz G.H., Bartsch J.A., Impact parameters related to post harvest bruising of apples. Transactions of the ASAE, 1989, 32, 953-957.
4. Chen P., Sun Z., Impact parameters related to bruise injury in apples. ASAE Paper No. 81-3041, 1981.
5. Holt J.E., Schoorl D., Mechanical properties and texture of stored apples. J. Text. Stud., 1984, 15, 377-394.
6. Hung Y.C., Prussia S.E., Determining bruise susceptibility of peaches ASAE Paper No. 88-6026 St. Joseph, MI: ASAE, 1988.
7. Gołacki K., Rowiński P., Dynamic measurement methods of fruit and vegetable mechanical properties. Acta Agrophysica 2006, 8, 67-82 (in Polish; English abstract).
8. Pang W., Studman C.J., Ward G.T., Bruising damage in apple-to--apple impact. J. Agric. Engin. Res., 1992, 52, 229-240.
9. Puchalski C., Brusewitz G.H., Apple bruise resistance determination using an electrical universal bridge. Int. Agrophysics, 2000, 14, 411-416.

ZALEŻNOŚĆ POMIĘDZY MASĄ I WYSOKOŚCIĄ ZRZUTU PODCZAS UDERZEŃ POWODUJĄCYCH OBICIA JABŁEK

Zbigniew Stropek, Krzysztof Gołacki

Zakład Teorii Maszyn i Automatyki, Akademia Rolnicza w Lublinie

Celem badań było ustalenie związku pomiędzy masą owocu, prędkością uderzenia i poziomem energii powodującej uszkodzenie tkanki miąższu jabłek. Jabłka były zrzucane na płaską sztywną powierzchnię przy różnych kombinacjach masy owocu i wysokości zrzutu. Następnie jabłka przechowywano w temperaturze pokojowej przez 5 dni, po których dokonywano klasyfikacji na uszkodzone i nieuszkodzone. Przeprowadzono również analizę regresji w celu znalezienia funkcji, która najdokładniej wyznaczałaby granicę pomiędzy nieuszkodzonymi i uszkodzonymi jabłkami przy określonych wysokościach zrzutu i masach owoców.