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EFFECT OF MASS ON IMPACT PARAMETERS OF APPLES

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Summary. In the article, an influence was determined of apple mass on the parameters characterizing material resistance such as: plastic deformation energy, energy absorbed during impact, dynamic yield pressure, maximum value of the reaction force, surface area of the impact contact. The principle of pendulum action was used at a measuring stand for impact tests and an apple was the striking element. Pinowa, Royal Gala and Florina apple varieties were tested. The apples of each varieties were divided into three groups depending on their masses (120g, 150g and 180g). The drop height of all the apples was 70 mm. For each variety and mass group 5 apples were tested. At each apple drop the reaction force during impact was recorded, the surface area of the impact contact was determined and the rebound height was calculated, which allowed to determine the value of energy absorbed during the impact. On the basis of the carried out experiments the statistically significant influence of apple mass on the contact surface area, peak of reaction force and energy absorbed during the impact was found. The total value of plastic deformation energy and dynamic yield pressure were independent of the mass.

Key words: impact, mass, apple, impact energy, absorbed energy, plastic deformation energy.

INTRODUCTION

The majority of damage occurring in fruit and vegetables results from mechanical impact appearing during harvest, transport, grading, handling and packing. It is necessary to know impact energy, absorbed energy, force response, impact velocity, rebound velocity and deformation course to fully find mechanisms of a fruit and vegetable reaction under the impact load and to determine their bruise susceptibility. Neither determination of impact velocity or impact energy nor force measurement generate large problems, whereas deformation measurement during the impact is more difficult to carry out and requires equipment of high sensitivity and data processing rate in very small measurement ranges. Therefore numerous studies fail to analyse the full impact process (consisting in an analysis of stress and strain state) and concentrate only on the determination of characteristic quantities (on the basis of force course in time) designed to define the indexes that are further used for fast and easy estimation of agricultural produce ripeness or quality.

Rohrbach [Rohrbach 1982] studied variability of blueberry reaction on the impact by dropping them on a force transducer with the specified height. By measuring the maximum value of the impact force F_p and total impact time t_c, he connected the firmness of blueberry by using the indicator $c_2 = F_p/t_p^2$ where t_p is the time to reach the peak force during impact.

Delwiche worked out a sorting line system [Delwiche 1989], in which c_2 parameter was used to grade peaches and pears into three categories: hard, firm and soft. Zhang [Zhang 1994] showed that the firmness of peaches is also closely correlated with the indicators $c_1 = F_p/t_p$ and t_c. In other studies [Wan 1997] maturity of plums were determined using c_1 and t_p parameters, while in case of grapes t_p and t_c parameters were applied.

In fruit and vegetables physical and chemical aspects of impact damage can be distinguished. The physical aspect is the mechanical failure of tissue. Bruise development as a result of the impact depends on the structure of the fruit's cellular tissue. The tissue of peach is characterized by densely packed cells and small, intercellular spaces filled up with air [Kunze 1975]. That is why it is susceptible to deep bruises invisible at skin surface. As a result of the impact, in this tissue structure, radial rupture and internal bruises in the form of cone will be developed. Whereas apple tissue has large intercellular spaces filled with air [Holt 1981]. During the impact the cells deform elastically at contact surface up to the moment of damage appearance. The limit between elastic and plastic (irreversible) deformation area moves into the fruit depths until the whole impact energy will be dissipated by damaged cells or stored in elastically expanded cell walls.

The chemical aspect is discoloration occurring in the bruise area as a result of enzymatic and nonenzymatic oxidation of the phenolic substrate participating in the reaction. As a result of the impact load, rupture of the cell membranes occurs as well as mixing the substrate with enzyme.

To study the susceptibility of plant materials to damage one can need indicators dependent not only on physiological changes in the damaged tissue or curve shape of impact course but most of all determined on the basis of material resistance. These parameters are bruise threshold, bruise resistance and dynamic yield pressure. The bruise threshold is the drop height, at which bruising of a sample occurs at a specified mass, shape and impact surface. The bruise resistance is the bruise energy divided by bruise volume. It is the inverse of the bruise volume at a specified drop height for a sample with a given mass.

An inherent problem of the method of fruit drop on a force transducer is the fact, that the impact force depends on the fruit mass and its curvature radius. Thus, a large variability of these parameters adversely affects the accuracy of the impact result estimation. An additional difficulty is a different drop height of the fruit at the specified setting of the measurement stand, resulting from the lack of a fruit with perfectly equal shapes. Thus, it is necessary to weighing all the dropped fruit every time, on account of the relationship between the impact energy and its mass. On the other hand, the fruit drop best expresses the actual impact conditions through the dissipation of the impact energy only in one place.

The aim of the study was to determine an influence of apple mass on the parameters characterizing material resistance such as: plastic deformation energy, energy absorbed during impact, yield pressure, maximum value of reaction force and bruise surface area.

MEASURING STAND

The pendulum principle was used at measuring stand for impact tests and an apple was the striking element. The pendulum consisted of a pair of supported fishing line, each 1m long to which a plastic plate with two tangs was fixed. An apple was fixed to the pendulum by the tangs. The force sensor was screwed into a sliding case clamped to a thick steel plate fixed permanently to a concrete wall. Moreover, a light titanium plate was screwed to the force sensor. Its diameter suited the fruit bruise area. The sliding case and the clamp-joint made it possible to arrange the fruit (fixed to the pendulum) in a vertical position to the plate at the impact moment, thereby perpendicular direction of the impact force to the impact surface was obtained. The stand was also equipped with control screws, which allowed arranging a girder (the pendulum rotation axis) in a position in which the impact force went through the center of the fruit mass. In that way the central collision conditions in the force sensor axis were met. An apple was placed at a requested drop height and remained there by means of suction pump. When the pump was turned off the fruit was released. The drop height was determined by means of a scale with plotted quantities corresponding to specified free fall values. In order to trigger the measurement we applied a laser – detector gate. The force measurement during the impact was carried out by means of the piezoelectric force sensor, model 2311-10 with sensitivity 2,27 mV/N and the measurement range ± 2200 N [Product specification]. It measures electric charge produced by deformed piezoelectric elements. The force sensor has a monolithic structure and is equipped with inner electric circuits, changing electric charge of piezoelement on voltage signal. The microprocessor recorder, which next transmitted data to a computer, cooperated with the force sensor. The sample frequency of the microprocessor recorder was 153,6 kHz.

MATERIAL AND RESEARCH METHOD

The subject of the studies were Pinowa, Royal Gala and Florina apple varieties. The measurements were carried out in November 2006. After the harvest the fruit was stored in a cold room and carried to the room with the temperature of 20şC a day before the research. The apples of each variety were divided into three groups depending on their masses (120g, 150g and 180g). In a given group the masses of an individual apple do not differ by more than 3%, hence, apple masses in separate groups had to be in the following ranges: 120±1,8g; 150±2,25g; 180±2,7g. The apple mass was measured by means of an electronic scale WPT 5 with accuracy of 0,2 g. The drop height of all the apples was 70 mm. This height was chosen using the results of the impact test research carried out earlier by the authors [Stropek, Gołacki 2007] with the aim of determining the apple bruise limit depending on their mass and drop height. The results showed that the bruise limit for an apple of 120g mass corresponded to the drop height of over 60 mm. For each variety and mass group 5 apples were tested. Each apple was dropped five times on the same spot from constant height. Before the last impact on the area of an expected apple bruise, the mixture of ink with chalk was marked for determining the surface area of the impact contact. The contact surface was calculated by means of the formula for the ellipse surface area:

$$P = \pi ab, \tag{1}$$

where: a, b – are the radiuses of major and minor of the ellipse axes.

At each apple drop the force response curve during the impact was recorded. To determine the rebound velocity after each impact, the time-course of the apple impact reaction force in time was integrated, which is equal to the impulse of the force. Next, using the formula where the impulse of the force is equal to the finite momentum change we calculate the rebound velocity v_{od}:

$$v_{od} = \frac{\int_0^t F(t) \cdot dt - v_u}{m}, \tag{2}$$

where: $F(t)$ – the course of the reaction force in time during the impact, m – apple mass, v_u – impact velocity, t – impact time.

The impact velocity v_u can be calculated by means of the formula:

$$v_u = \sqrt{2gh}, \tag{3}$$

where: h – apple drop height, g – gravitational acceleration.

Knowing the rebound velocity from the energy conservation law we determine the rebound height:

$$h_{od} = \frac{v_{od}^2}{2g}, \tag{4}$$

The value of the absorbed energy during the impact can be determined by the formula:

$$E_{poch} = mg(h - h_{od}). \tag{5}$$

RESULTS AND DISCUSSION

The correlation coefficients between the parameters characterizing material resistance and the mass for the three tested apple varieties are presented in Table 1.

Table. 1. The value of correlation coefficients between the parameters and the mass for three apple varieties

Variety	Relative stabilized rebound height	Contact surface area	Peak reaction force	Yield pressure	Plastic energy	Absorbed energy
Florina	-0,86*	0,80*	0,90*	-0,44	0,49	0,97*
Royal Gala	-0,68*	0,85*	0,90*	-0,42	0,35	0,96*
Pinowa	-0,14	0,87*	0,92*	-0,17	0,65*	0,92*

* indicates statistically significant values by p<0,05

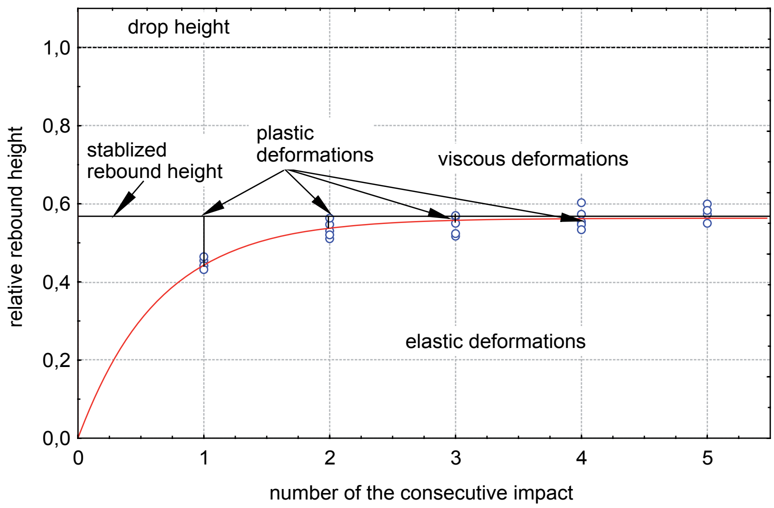

Fig. 1. A typical course of rebound height in a multiple drop technique at the same height

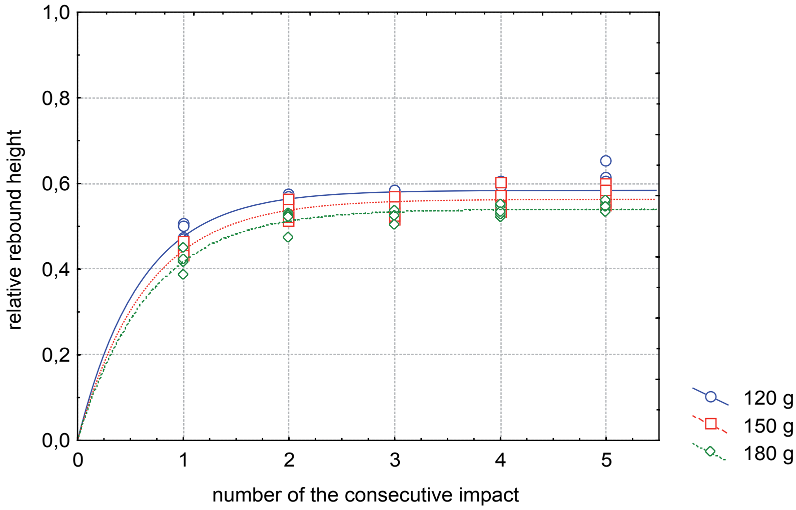

Fig. 2. A model graph of mass influence on relative rebound height for Florina apple variety

To determine bruise resistance, a multiple drop technique from a fixed height was used. It consists in fruit dropping several times in the same location at fixed drop height up to the rebound height stabilization. In the case of apples it requires from 3 to 5 impacts (Fig.1.).

The method of a multiple drop at the same height enables a division of the impact energy into elastic, viscous and plastic deformation energy. The viscous energy is connected with the losses resulting from vibrations. It assumes, that the viscous looses are constant for each impact at a given height. Therefore, the bruise energy being the plastic deformation energy can be in approximately determined as the difference between the impact energy and the sum of the elastic and viscous deformation energy. The total bruise energy is then the sum of plastic deformation energy of the separate impacts (Fig. 1.). While determining the total bruise energy, it was assumed, that there are no plastic deformations after the fifth impact. As Table 1 shows, the mass does not have a strong influence on the plastic deformations.

The relative rebound height is the rebound height divided by the drop height. The relative stabilized rebound height (after the fifth impact) is proportional to the energy recovery degree during the rebound. The higher lies the asymptote of the rebound height, the larger part of the impact energy is returned in the form of the elastic deformation energy, whereas the smaller part is turned into the work of the gases and liquids flow in the intercellular spaces. Therefore, the relative stabilized rebound height can be also the measure of apple bruise resistance.

Yield pressure was determined as the quotient of an average value of the maximum reaction force from the last three impacts to the bruise surface area measured after the last impact. After several impacts at the same height the bruise surface area is so large as to dissipate the impact force not causing additional damage. Thus it is assumed, that the pressure value is equal or not much smaller than yield pressure of the undamaged tissue. In this case high values of the correlation coefficient depending on the mass were not obtained. It can be proved, that yield pressure should be treated as a material constant associated with the critical stresses of the cellular tissue.

The energy absorbed during the impact was determined by the formula (5), moreover, for the rebound height, the value of stabilized height after 5 impacts was inserted. For each variety were obtained high correlation coefficients were obtained (Tab. 1.). The statistical significance of differences between the average values of absorbed energy for different mass values of the tested apple was found.

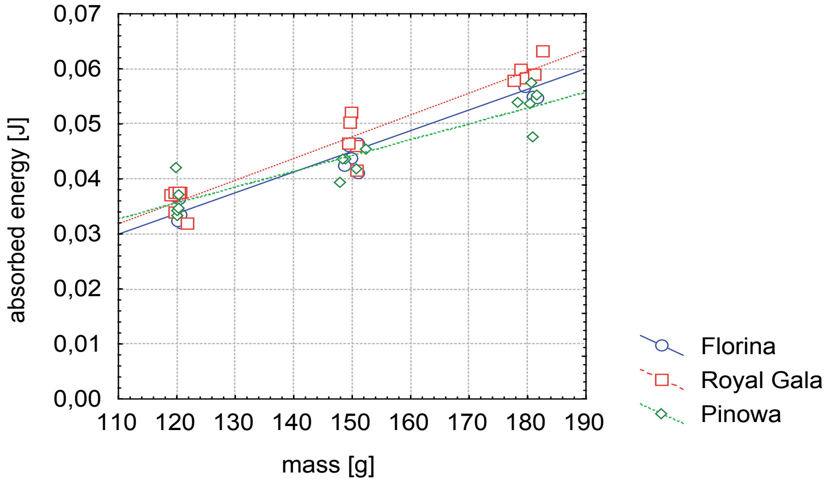

Fig. 3. The relationship between the energy absorbed during the impact and the mass for three apple varieties

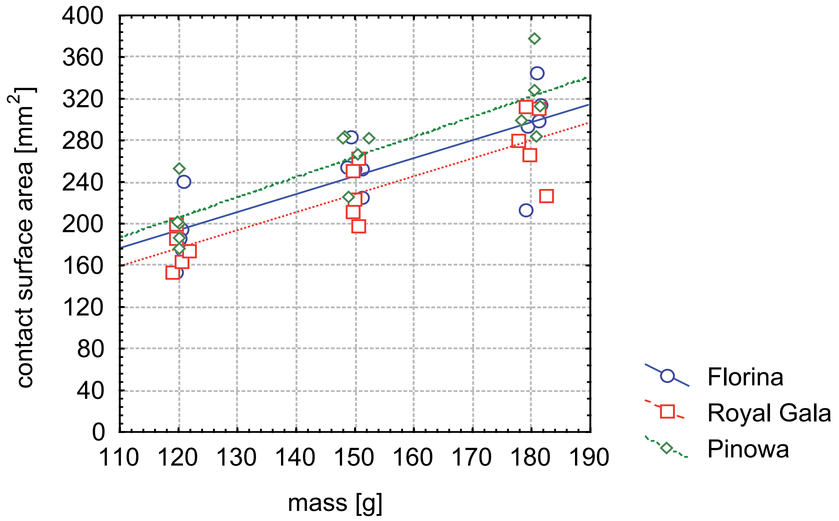

Fig. 4. The relationship between the contact surface area during the impact and the mass for three apple varieties

The contact surface area during the impact was calculated by means of the formula (1). To determine the relationship between the reaction force and the mass, the maximum value of the reaction force recorded during the last impact was taken. The statistically significant influence of the mass on the value of the contact surface area and the value of the peak reaction force was found. It was additionally confirmed by high correlation coefficients (Tab.1.).

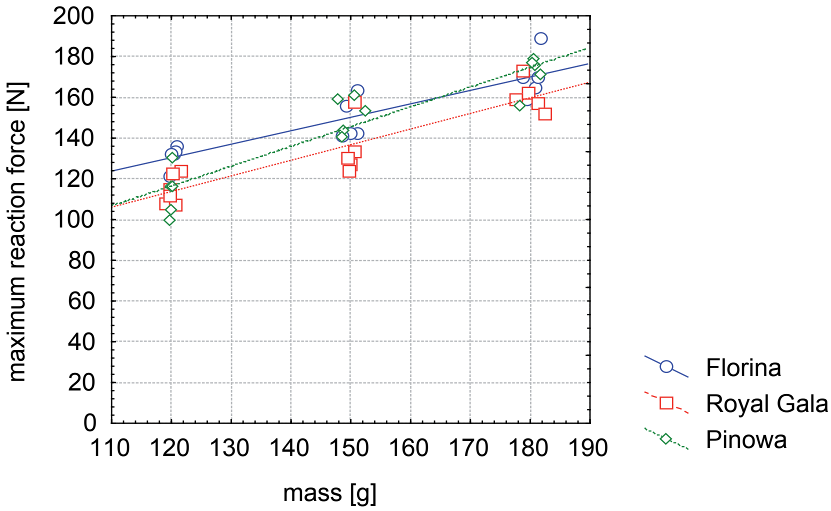

Fig. 5. The relationship between the peak reaction force during the impact and the mass for three apple varieties

CONCLUSIONS

1. The statistically significant influence of apple mass on the contact surface area, the peak reaction force and the energy absorbed during the impact was found.
2. In the carried out experiment, the apple mass did not have an influence on the value of plastic deformation energy and dynamic yield pressure.
3. The relative stabilized rebound height was highly correlated with the apple mass of Florina and Royal Gala varieties. However, statistically significant differences between the average values of rebound height for different mass values were not obtained.

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Product specification: "ISOTRON Force Sensor – ENDEVCO model 2311-10"