

BRUISE RESISTANCE OF APPLES (MELROSE VARIETY)

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Summary. The paper includes the results of the impact research on apples of the Melrose variety dropped onto the force sensor from different heights. Force-time profiles, bruise area and volume were recorded. To determine bruise resistance, the CHMI technique (constant height multiple impact) was adopted. The five impact heights which guaranteed the bruise incidence at dropping were selected: 20 mm, 35 mm, 50 mm, 70 mm, 80 mm. Based on the research results, it was stated that bruise resistance coefficient in function of impact height for fresh and stored apples proved to be the lowest for the low impact heights (20 mm) and it increased by several times along with the height drop. Mathematical model for the rebound height stabilisation process during consecutive impacts by the exponential function was proposed.

Key words: apples, bruise resistance, impact.

INTRODUCTION

Fruit and vegetables of soft tissues, like apple, pear, grape and potato are exposed to mechanical forces which lead to bruising, which in turn has the potential to cause their quantitative losses and is a serious hazard to quality. Impact damaging is of common occurrence at each stage of the technological process and, practically, it has been difficult to eliminate in the large-scale production. Besides, bruise is not likely to be detected immediately, because skin discoloration develops within approximately 24h. Therefore, minimizing bruising rate often makes the priority while designing and modernizing the technological lines, handling strategies or storage. As a rule, impact damage occurs while dropping fruit against hard surfaces of machine elements or other fruit. Considering postharvest physiology, bruising induces fracture of cell membranes, burst of intercellular bonds and cellular fluid loss. Most tests that served as the basis for impact damage mechanisms analysis were performed under the quasi-static loading conditions [Holt & Shoorl, 1977; Blahovec, 1999; Busevitz & Bartsch, 1989]. The static loading occurs at low deformation velocity of plant material. Thus, at low velocity and the sufficiently long loading time, fluids and gasses in cells and loaded tissues are able to migrate to the unloaded parts of tissue. It was stated that stress-relaxation times expressed as coefficients of generalized Maxwell model, may show differences even by two orders of magnitude when the deformation velocity was changed starting from decimal parts of millimeter to meters per second [Gołacki, 1998]. It should be emphasized, that under dynamic loading conditions, inertia effect reported in deforming fragments related to their mass becomes critical as well

as the fact of stress wave transfer and its potential superposition, which does not occur under the quasi-static loading conditions.

The above-mentioned facts have proved the necessity to determine apple resistance to bruising at damaging impact conditions where a plastic deformation rate per energy unit and deformation size is much greater.

Bruise resistance (bruise energy per unit of bruise volume) is one of the objective indices employed to evaluate apple susceptibility to damaging impact. The other indices include bruise threshold (the drop height at which bruising begins to occur for an apple of given mass, shape and impact surface) [Bajema & Hyde, 1998] and threshold of material plastic flow (maximum dynamic stress at which no further bruise damages are observed). The components of bruise resistance, like bruise area, its shape, depth and volume may be determined using the procedure described by Holt [Holt & Schoorl, 1977].

There are numerous factors affecting apple sensitivity to bruising. The major one proves to be the drop height and area profile during the impact. Still, a number of post-harvest factors, i.e. maturity, water potential, storage time, water content, firmness and mass are of importance as well. Van Zeebroeck [Van Zeebroeck *et al.*, 2007] reported a slight decrease in bruise resistance of apples at temperature 1°C compared to those stored at the room temperature.

Awareness of the conditions contributing to damage resistance response of fruit and vegetables to cultural and conditioning processes should be created among the growers (fruit harvesters) as well as post-harvest handling transport personnel, store house workers, fruit processing plant staff and, finally, fruit sellers. At each technological stage, apples are exposed to varied outer conditions (temperature, pressure, moisture etc.). Fresh apples supplied to shops immediately after harvest, are usually characterized by the same firmness, water content and water potential. Stored apples, however, are affected by some additional factors, like storage time, the secondary storage time as well as the outer conditions at storage. It is clear that the general physical condition of apples held under storage deteriorates, but the question is whether fruit is less susceptible to bruising at that time. Klein [Klein, 1987] showed that bruise damage of apples decreases with increasing storage time. Brusewitz [Brusewitz & Bartsch, 1989], however, reported a completely contrary view.

The objective of the present research was an employment of CHMI technique to determine impact damage resistance of apples Melrose variety dropped from varied damaging heights for both fresh apples and post-storage ones.

MATERIAL AND METHODS

The investigations included apples Melrose variety supplied by the Agricultural Experimental Station of the University of Life Sciences in Lublin. Apples were dropped from several drop heights onto force sensor. There were recorded the force-time profiles, bruise area and volume as well as specimen mass. To establish bruise resistance and threshold of material plastic flow, the technique of constant-height multiple-impact (CHMI) was employed [Bajema, Hyde 1998]. The studies were performed on healthy, undeformed apples whose mass averaged from 167 up to 265g and diameter within 76,6 – 91,8 mm. The first research series was conducted on the day following harvest, while the second after the 4-week-storage at temperature of about 20°C. The following five impact heights were chosen: 20mm, 35mm, 50mm, 70mm, 80mm. The damaging heights guaranteed bruise occurring at dropping as the earlier-determined bruise threshold for the examined variety ranged within 14-18mm. The test was done in five replications for each impact damage height. The stand for studying whole commodity bruising energy was depicted in the paper [Gołacki & Rowiński, 2006].

RESULTS AND DISCUSSION

The procedure for bruise energy measurement that equals plastic deformation energy is shown in Fig. 1.

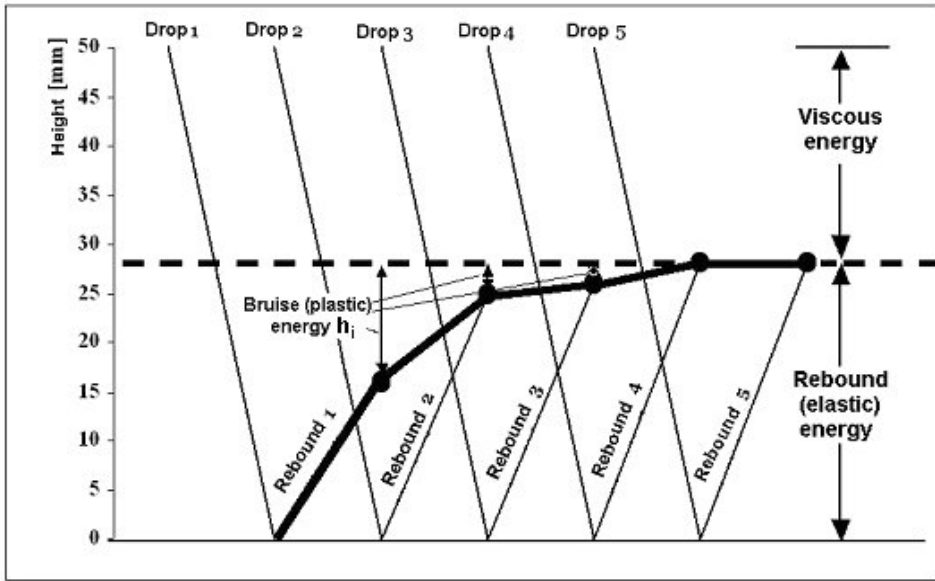


Fig. 1. Method for bruise energy determination. Impact height line segments are calculated into energy individually for each apple, concerning its mass

The sum of line segments depicting plastic deformation at subsequent damaging impacts allows to determine the bruise energy for a particular apple of given mass using the following formula:

$$H_{reb} = A(1 - e^{-\frac{N_i}{B}}),$$

where: m - mass of apple, g - gravitation.

Figure 1 also illustrates a fact of a steady decrease of plastic deformations at several damaging impacts until the rebound height has stabilized and thus, the contact area stabilizes as being large enough to distribute the impact forces without any further tissue damage.

The exemplary force-response courses at the first and last impact of the same apple in fresh state are presented in Fig. 2 and 3. Figure 2 shows that the surpassing of 170 N impact force induces rupture of tissue structures and, as a consequence gas and fluid migration to the areas of a lower pressure. As for the last impact (Fig. 3), where rebound height is stabilized, there was recorded a regular curve shape, without local declines of force-response value. In this case, no further deformations of a plastic nature are observed.

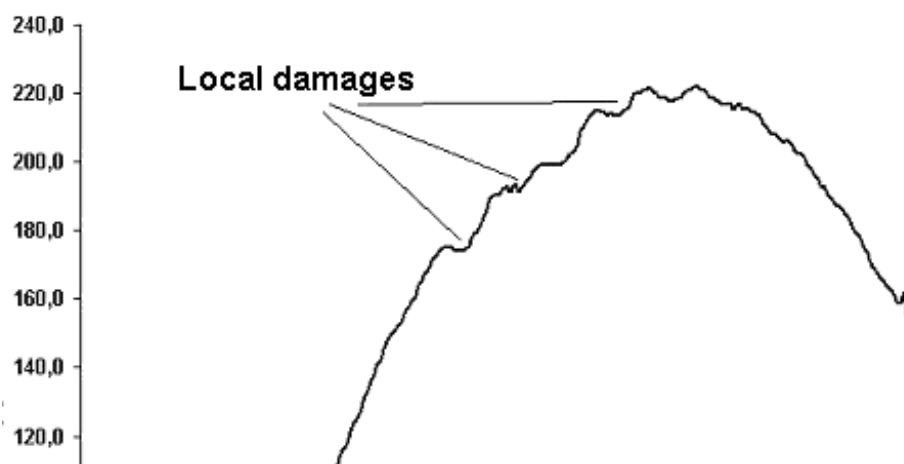


Fig. 2. Force course in the time function recorded at the first impact from 70 mm height, fresh apple

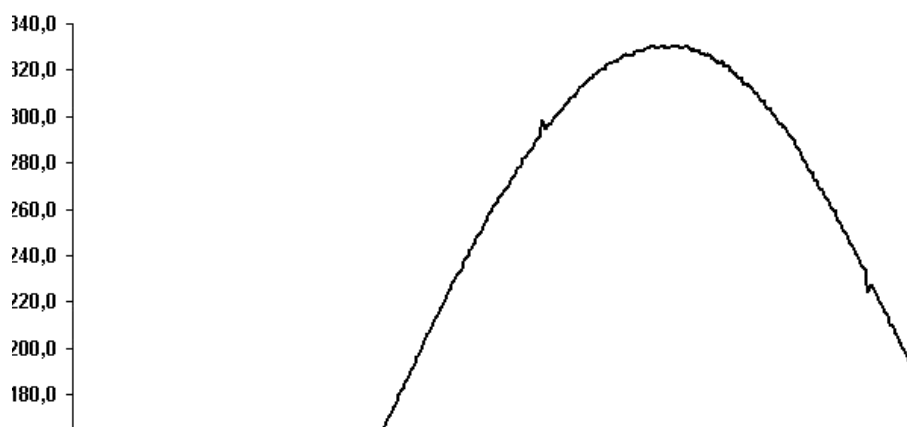


Fig. 3. Force course in the time function recorded at the last impact from 70 mm, fresh apple

A regular course of force-response curves was observed in the case of apples after storage (Fig. 4). The apples demonstrated lower turgor and higher gas amount in the intercellular spaces. Hence, under low loading conditions, despite approximated deformation value, less tissue structure damage developed there.

Bruise resistance coefficient in the function of impact height for fresh and stored apples is presented in Fig. 5. Impact damage resistance appeared to be the smallest for low drop heights and grew several times as impact height increased within the studied height range. It is a disadvantageous effect giving the evidence of the highest bruise susceptibility of apples Melrose variety while dropping from low heights.



Fig. 4. Exemplary force-response curve recorded at the first impact from 70 mm height, apple after storage

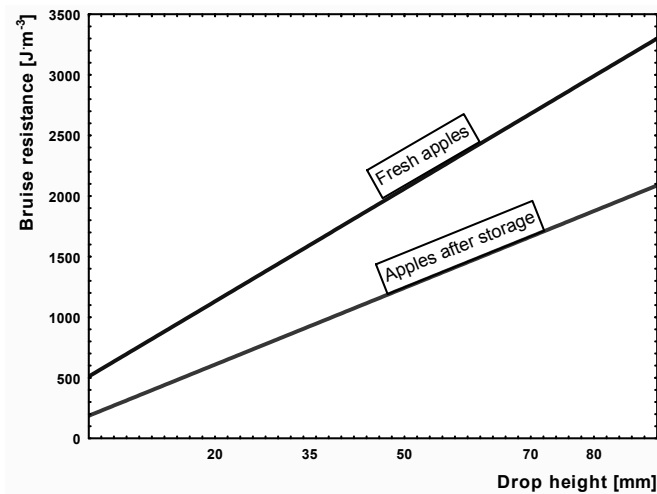


Fig. 5. Dependence of bruise resistance coefficient on impact height for fresh and stored apples

Higher values of bruise resistance coefficient (BRC) were established for fresh apples within the whole studied range of damaging heights. That may imply that fresh apples develop less interior damages under the identical impact conditions compared to stored apples. It is a drawback of the commonly applied BRC. As it has already been mentioned, this coefficient is defined as a ratio between bruise energy and bruise volume. Under low loading conditions, over-dried apples after storage can show elastic deformation without any permanent damage of the inner structure (Fig. 4). Therefore, the explicit association of bruise resistance coefficient and amount of inner micro-damages observed at different stages of apple storage process is not justified.

On the grounds of the research results, a model was proposed for rebound height stabilization through approximation of mean rebound heights for varied drop heights:

$$H_{reb} = A(1 - e^{-\frac{N_i}{B}}), \quad (1)$$

where: H_{reb} - rebound height, N_i - consecutive impact, A and B - constant.

Approximation of the mean rebound height courses for fresh apples and after storage are presented in Fig. 6 and 7.

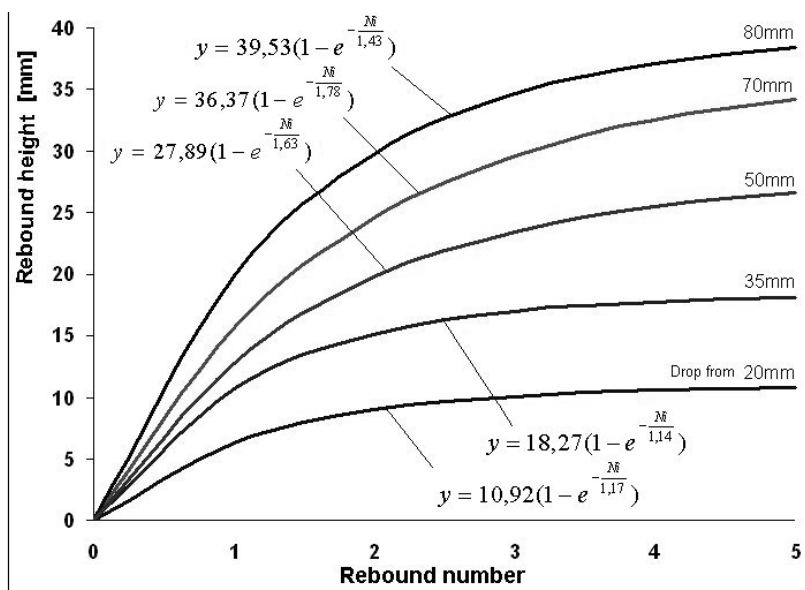


Fig. 6. Approximation of mean courses for fresh apples

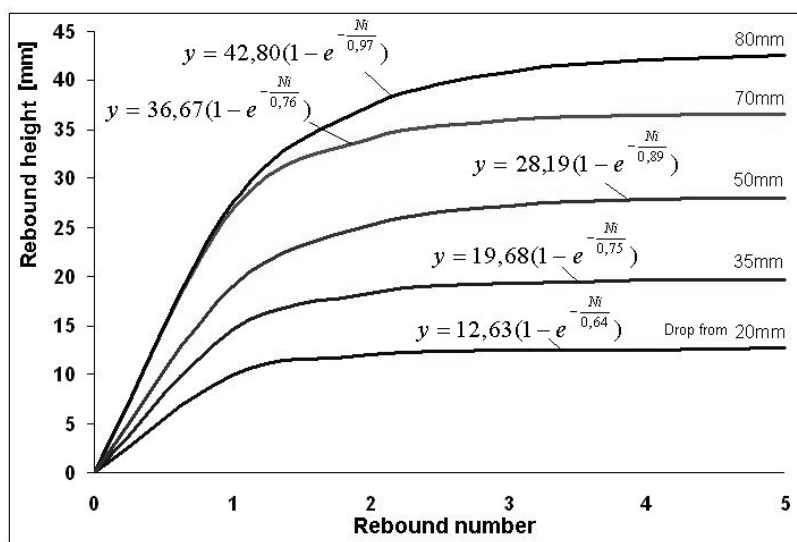


Fig. 7. Approximation of mean courses for apples after storage

The curve courses show that the rebound stabilization process proceeds faster for apples after storage. The constant A may also be expressed in per cent, as a dependence (2):

$$A = \frac{h_{\text{stabilized}}}{h_{\text{drop}}} [\%]. \quad (2)$$

In this case, the constant A correlates to elastic deformation energy percentage in the total impact energy in the state of rebound height stabilization. Fresh apples exhibit higher resistance and require more energy to obtain rebound stabilization state. The constant B in the equation (1) may be interpreted as the time constant of the rebound stabilization process at consecutive damaging impacts. The values of this constant prove to be lower for apples after storage in all the drop heights. As for stored apples, their rebound stabilization was also determined at higher rebound heights for all the impact heights. This fact proves higher elastic deformation rate for this fruit at rebound stabilization. It is clear that, as in the fresh apple intercellular spaces, more fluid (higher turgor state) is present that gradually relocates to the areas transferring lower loading at the subsequent rebounds. A stabilized rebound value is characterized by the constant A (1).

Figure 8 illustrates the maximum dynamic stress occurring at the last impact for each mean drop height. Then, the stabilized rebound area distributes impact forces without any tissue damage development. A ratio between the impact force and its contact area is expected to approach the constant value for all drop heights.

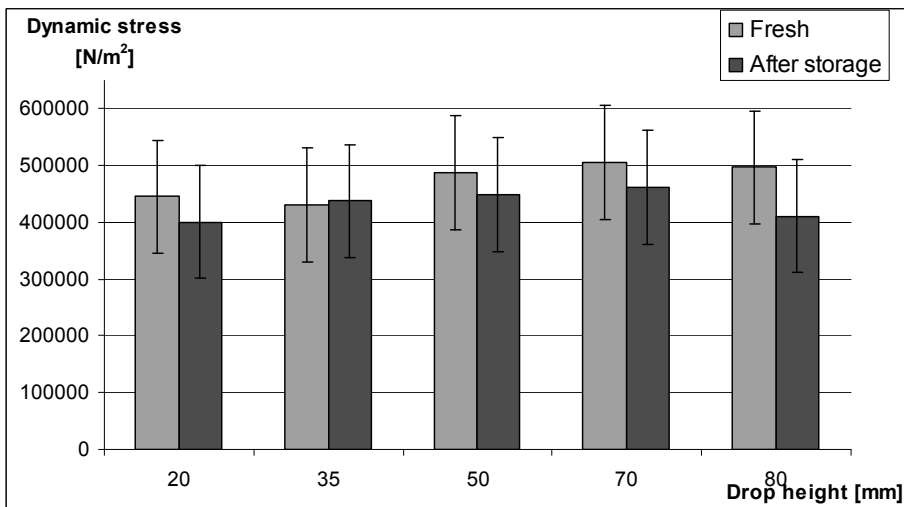


Fig. 8. Mean values of maximum dynamic stress transferred by stabilized rebound area for all the drop heights

No statistically significant differences were recorded between the maximum stress values at varied impact heights for both fresh apples and after-storage ones.

CONCLUSIONS

1. A dramatic increase was stated of bruise resistance coefficient of apples Melrose variety with increasing drop height, and at the same time the lowest bruise resistance at 20 mm drop height.

2. It was confirmed that apples after storage exhibited lower bruise resistance than the fresh ones.
3. The proposed mathematical formula of rebound height approximation in the subsequent impacts by the exponential function facilitates the interpretation of rebound stabilization effect and proves that A and B coefficients possess the physical interpretation.
4. The critical stress values calculated for varied drop heights did not demonstrate any statistically significant differences.

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ODPORNOŚĆ NA OBICIA JABŁEK (ODMIANA MELROSE)

Streszczenie. W artykule przedstawiono wyniki badań testów udarowych przeprowadzonych na jabłkach odmiany Melrose zrzucanych na czujnik siły z różnych wysokości. Podczas eksperymentów rejestrowano przebieg siły w czasie oraz mierzono powierzchnię i objętość obicia. Do określenia odporności na obicia zastosowano technikę CHMI (wielokrotnego uderzenia ze stałej wysokości). Wybrano 5 wysokości rzutu: 20 mm, 35 mm, 50 mm, 70 mm, 80 mm, które zapewniały wystąpienie obicia przy każdym uderzeniu. Na podstawie wyników badań stwierdzono, że odporność na obicia dla świeżych i przechowywanych jabłek była najmniejsza dla małych wysokości rzutów (20 mm) i wzrastała kilka razy wraz ze wzrostem wysokości rzutu. Zaproponowano również matematyczny model przebiegu stabilizacji wysokości odbicia podczas kolejnych uderzeń w postaci funkcji wykładniczej.

Słowa kluczowe: jabłko, odporność na obicia, uderzenie.