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THE DETERMINATION OF APPLES BRUISE RESISTANCE BY THE MULTIPLE IMPACT METHOD

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K e y w o r d s: bruise resistance, impact, apple.

A b s t r a c t

In this paper an attempt was undertaken aiming at establishing a methodology determining bruise resistance and the influence of apple storage time on its value and variability. The bruise resistance is a quotient bruise energy to bruise volume. The method applied to determine bruise resistance is the method of multiple drop at a constant height. It consists in multiple dropping of a tested fruit at a constant height up to stabilizing of a rebound height. The research was carried out in two time limits. The first time limit directly after the harvest and the second time limit after a four-month storage period. The measurements were performed on Melrose variety apples. On the basis of the experimental studies of apples mechanical properties under impact loading conditions, the small variability of the bruise volume in the separate research time limits was obtained. In connection with it, the main factor of the bruise resistance variability is the bruise energy.

WYZNACZANIE ODPORNOŚCI NA OBICIE JABŁEK METODĄ WIELOKROTNEGO UDARU

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S ł o w a k l u c z o w e: odporność na obicie, uderzenie, jabłko.

A b s t r a k t

W pracy podjęto próbę określenia metodyki wyznaczenia odporności na obicie oraz wpływu czasu przechowywania jabłek na jej wartość oraz zmienność. Odporność na obicie jest to stosunek energii obicia do objętości obicia. Metoda stosowana do wyznaczania odporności na obicie to metoda wielokrotnego zrzutu ze stałej wysokości. Polega na kilkukrotnym zrzucaniu badanego owocu ze stałej wysokości aż do ustabilizowania się wysokości odbicia. Badania wykonano w dwóch terminach: termin pierwszy – bezpośrednio po zbiorze, termin drugi – po czteromiesięcznym okresie przechowywania. Pomiary przeprowadzono na jabłkach odmiany Melrose. Na podstawie badań eksperymentalnych właściwości mechanicznych jabłek w warunkach obciążeń udarowych uzyskano małą zmienność objętości obicia w poszczególnych terminach badań. W związku z tym głównym czynnikiem zmienności odporności na obicie jest energia obicia.

Introduction

In Poland every year on average about 2 million tons of apples are picked up (KIERCZYŃSKA 2005, DOBRZAŃSKI 2006). According to the Central Office of Statistics data in apple production, which Poland is a leading global producer, the losses caused by impacts, are estimated at the level of 15 %. It is a quotient of apples mass picked up in an orchard to apples mass placed in a storehouse. At this harvest size and level of generated losses, assuming an average price for 1 kilo of apples around 1 zloty, financial losses of several hundred million zlotys are developed. To quantitative losses it should be also added̕ lightly damaged' apples, which were allowed to further production stages and whose quality and market value fell considerably. Apart from economical aspects there is still another equally important, aspect connected with the environment protection. It should be emphasized that such a large mass of damaged, rotten apples effects the natural environment. During putrefaction a lot of toxic substances are produced, of which liquid ones land in soil and gaseous ones mix in the air. This substances are responsible for degradation of the environment and are also the cause of many diseases and allergies among people and animals.

Above mentioned consequences of mechanical damage became a reason for researching and describing the phenomenon of fruit and vegetables susceptibility to mechanical loading. Not only is it important to explain the phenomenon of strain arising, causing apple tissue destruction but also to undertake some attempts connected with minimalization of the damage effects.

Correct determination of apple susceptibility under impact loading requires an application of indicators, whose values will be not dependent on physiological changes in tissue (KNEE 2002, AMIOT 1992, SAMIM 1993), and will be determined rather on the basis of the material strength. From among them it can be singled out a bruise resistance. The bruise resistance is a quotient bruise energy to bruise volume. There was developed a lot of research techniques to determine this indicator (CHEN 1991, ZHANG 1994, BAJEMA 1995, CHEN 1995, MATHEW 1997, MCGLONE 1997, BARITELLE 2001, VAN ZEEBROECK 2007). The method applied to determine bruise resistance and more accurate one of its components – bruise energy is the method of multiple drop at a constant height. It consists in multiple dropping of a tested fruit at a constant height up to stabilizing of a rebound height. The stabilizing of a rebound height takes place, when separate drops caused such damage to apple tissue and increasing of contact surface area, that the next drops do not cause any further, additional damage. On the basis of obtained rebound height are determined elastic deformation energy, viscous deformations energy and bruise energy (plastic) (HOLT 1977, BAJEMA 1998). To establish bruise resistance it is also essential determining bruise volume. The total bruise volume is the sum of bruise volume above and below the contact surface (HOLT 1977).

In this paper an attempt was undertaken aiming at establishing a methodology determining bruise resistance, which describes apple susceptibility on mechanical damage, and the influence of apple storage time on its value and variability.

Materials and methods

The research was carried out in two time limits. The first time limit directly after the harvest and the second time limit after four-month storage period. The measurements were performed on Melrose variety apples. 50 apples in total were tested. Measuring series were every 7 days at 10 apples for 28 days. In the second time limit, the research period, the amount of measuring series and the amount of apples in separate series was analogous to the first research time limit. In the both time limit the apples chosen for the studies were not selected. Before the right impact test mass fruit and maximum diameter fruit measurements were carried out. The temperature in the research room changed in the 18–21degree range. It is the temperature, in which apples often are stored in retail both on a shop shelf and at consumer's home (DOBRZAŃSKI 2006).

The impact test was carried out on the measuring stand acting on the rule of pendulum, in which an impacting element was an apple dropped on a plate attached to an undeformable steel sheet. The measuring stand was also fitted with the scale with marked quantities corresponding to specific free fall height values. An apple placed at a definite drop height and held by means of a suction pump was next released through its shutdown.

Bruise resistance measurement

Bruise energy was determined by the multiple drop method at a constant height. The most important element of the technique is recording rebound height, which was made by means of an angle scale and a digital camera (Fig. 1).

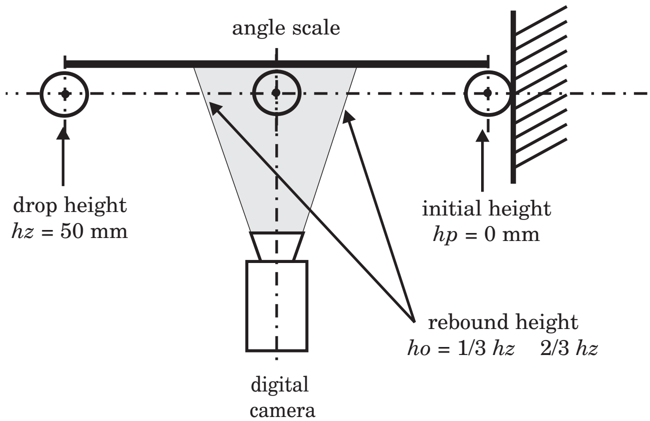

Fig. 1. The diagram of apple movement recording by the camera – view from above

Each apple was dropped six times at the same height. Stabilizing of rebound height took place already at the fourth drop. To make sure, that the rebound height stabilized , two drops were still recorded. During the preliminary research the drop height was so selected that the height of the first rebound was equal of the 1/3 drop height (BAJEMA 1998). It was stated, that over 90% of apples meets this criterion for the 50 mm drop height. The recorded film of the drop and rebound courses was transferred to a PC computer. By means of a specialist video software the recording was analyzed and the rebound height was read out for separate drops. On the basis of the data from the experiences for an each apple were created the graphs representing energy distribution in separate drops (Fig. 2.).

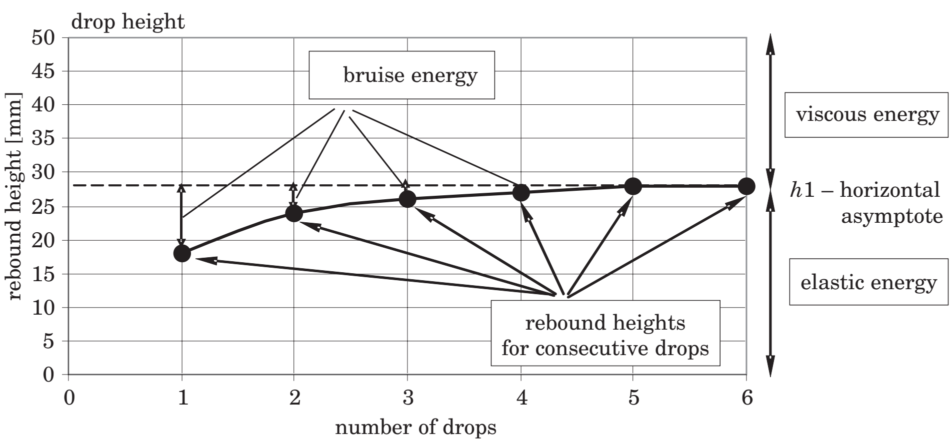

Fig. 2. Determining the rebound energy on the basis of the rebound height

The appropriate energy values, which are marked in the figure, are obtained by multiplying suitable heights by apple mass and gravitational acceleration.

The graph is formed through marking rebound height for consecutive drops. As it is seen in figure 2 after the first impact the rebound height of an apple is the lowest in comparison with other impacts. It shows, that during the first drop a large part of the impact energy is dissipated on permanent tissue deformation. During the consecutive rebounds the participation of elastic energy in total impact energy increases. After the fourth impact the rebound height stabilizes, which was marked by $h1$ horizontal asymptote. From this impact the consecutive drops trigger fewer and fewer permanent deformations of apple tissue. It can be stated, that for separate impacts the rebound height value represents elastic deformations energy. However, the segment from the height determined through the $h1$ asymptote to the drops height represents viscous deformations energy for a single impact. Irreversible deformation energy (plastic energy) that is permanent destruction of tissues represents the middle segment between the rebound height and the $h1$ asymptote. Thus the sum of segments between the rebound height value for the consecutive impacts and the $h1$ asymptote presents a total plastic deformation energy that is bruise energy.

The second element essential to determining bruise resistance is bruise volume. For this purpose after carrying out the research, bruised apples were left up to the moment of bruise discoloration. The manner of determining bruise volume of spherical shaped material represents Figure 3 (Holt 1977).

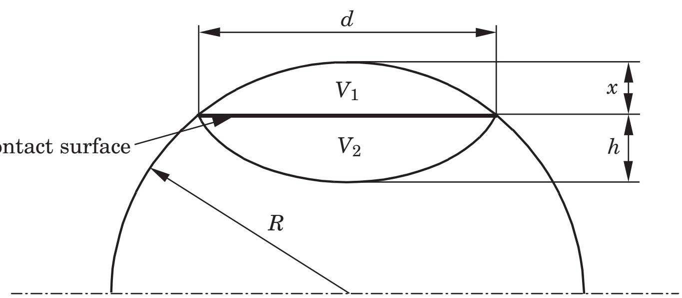

Fig. 3. Determining bruise volume

On the basis of d and h measured quantities V_1 bruise volume below contact surface can be determined:

$$V_1 = \frac{\pi h}{24} (3d^2 + 4h^2) \tag{1}$$

where: h is the bruise depth below the contact surface and d is the diameter of the contact surface area.

The diameter d was estimated on the basis of the contact surface area, established as a circle, reflected on a piece of paper. It was performed by means of a colouring substance, which was put on an apple in the place of an expected bruise before carrying out the last impact.

Similarly to the equation (1) bruise volume V_2 above the contact surface can be calculated:

$$V_2 = \frac{\pi x}{24}(3d^2 + 4h^2) \tag{2}$$

where: x is the bruise depth above the contact surface

The total bruise volume is therefore the sum of volumes below and above the contact surface

$$V = V_1 + V_2 \tag{3}$$

Results and discussion

Bruise energy is a part of the total impact energy, which triggers off tissue and plant cells damage that is irreversible changes. The curves of the energy distribution for a single apple were determined by recording the rebound heights in the consecutive drops at a constant height of 50 mm (Fig. 4).

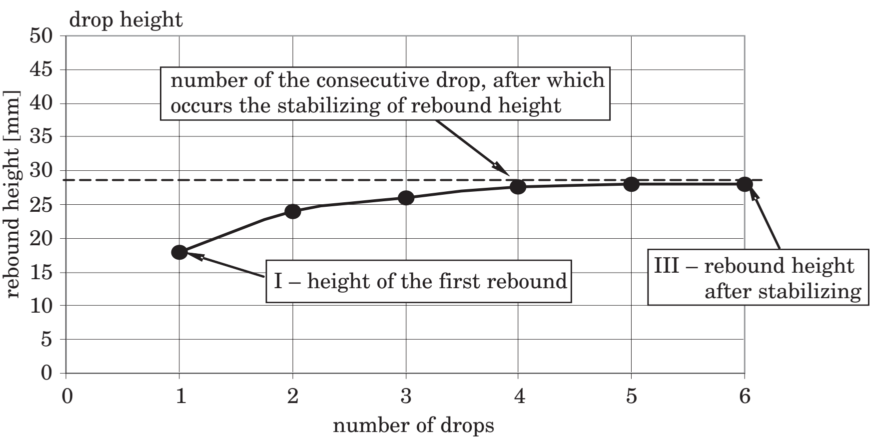

Fig. 4. The illustrative curve of the rebound stabilization process for Melrose variety apple directly after the harvest

The sum of segments between the individual rebound heights and the rebound height after stabilizing is bruise energy. The analysis of energy distributions shows size of permanent apple damage after consecutive impacts. For further analyses three characteristic points on the graph of energy distribution were selected (Tab. 1):

I – the height of the first rebound;

II – the number of the consecutive drop, after which occurs stabilizing of the rebound height;

III – the rebound height after stabilizing.

Table 1

Average values describing characteristic points for Melrose variety apples

Specification	Characteristic points	Consecutive research weeks				
		week 1	week 2	week 3	week 4	week 5
Apples directly after harvest	I [mm]	14	15	17	19	20
	II	5	5	5	5	5
	III [mm]	27	27	27	28	28
	average bruise energy [J]	**0.027**	**0.019**	**0.016**	**0.012**	**0.010**
Apples after four-month storage period	I [mm]	17	18	18	19	18
	II	2	2	2	2	2
	III [mm]	24	24	22	22	20
	average bruise energy [J]	**0.014**	**0.013**	**0.007**	**0.008**	**0.005**

The bruise energy value is determined directly through the above mentioned characteristic points. The bigger the difference between the first rebound height and the rebound height after stabilizing and the later stabilizes rebound height the higher value reaches the bruise energy.

Also the bigger value of the rebound height after stabilizing at the same height of the first rebound the bigger will be the rebound energy.

Collected in Table 1 data shows how long-term storage influences bruise susceptibility of apples. The bruise energy is closely connected with plastic deformations energy and elastic deformations energy. During the consecutive impacts the nature of deformations change. To the moment of rebound height stabilizing in consecutive impacts occur plastic deformations, which trigger off the permanent change of apple tissue structure. After four impacts occurs stabilizing of the rebound height which shows, that in an apple takes place only viscous and elastic deformations. The consecutive drops after stabilizing do not cause further permanent deformations. The bruise energy reaches the biggest value for apples, which require a larger number of drops for stabilizing the rebound height.

The bruise volume was determined on the basis of the contact surface area for the last drop and the bruise depth after discoloration that is about 24 hours after the measurement.

The bruise depths x and h were measured by calliper with accuracy of 0.1 mm after cutting an apple in the perpendicular plane to contact surface and going through the middle of the apple.

The total bruise volume is the sum of the volume above and below the contact surface (equation 3). For the studies were selected apples, whose shape was similar to the sphere, hence the curvature radius depends on an apple size that is also on its mass. In relation to it the bruise energy was higher for the apples with a larger mass. The storage time depended more on bruise discoloration than its size, because average values of the bruise volume during this period changed to a small degree. It results from the fact, that in the consecutive weeks of the storage, the apple skin is more and more creased and becomes a natural protective barrier for apple tissue more and more susceptible to bruise.

Apples directly after the harvest

In Figure 5 were presented the average energy distributions in the separate research weeks for apples directly after the harvest.

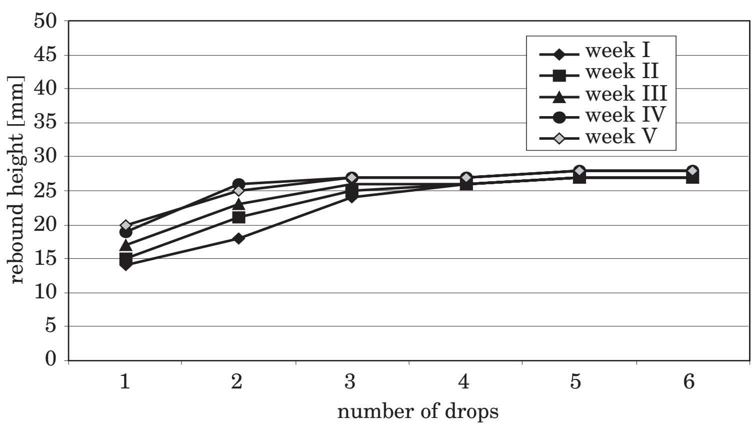

Fig. 5. The average values of rebound height in the consecutive research weeks for Melrose variety apples directly after the harvest

The energy distributions in the separate research weeks for the three first drops showed, that the plastic deformations energy for the consecutive drops decreases, thereby the elastic deformations energy increases. However, in the three consecutive drops permanent deformations energy value reaches already small values close to 0, which causes elastic deformations energy to remain of the same level in practice. The curves approach asymptote, showing that contact surface area reaches such a size, which determines the occurrence of the stress values not causing already subsequent tissue damage.

Apples after the four-month storage period

The data analysis was carried out similarly to apples directly after the harvest. The average bruise distributions in the consecutive research weeks were showed in Figure 6.

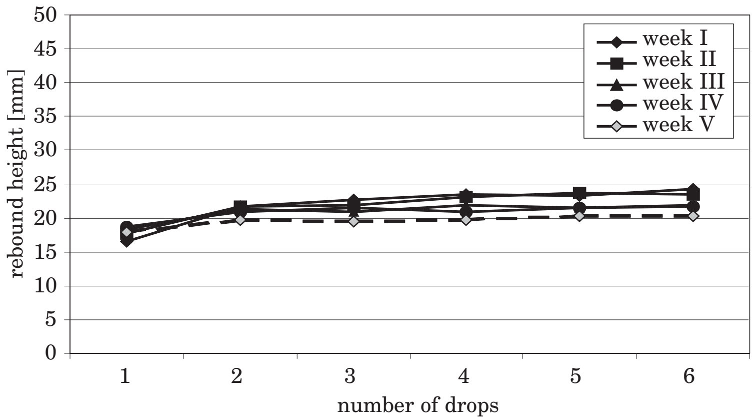

Fig. 6. The average values of rebound height in the consecutive research weeks for Melrose variety apples after the four-month storage period

In comparison to apples directly after the harvest (Fig. 5) it can be noticed, that the tested apples are noted for smaller plastic deformations energy values during the consecutive drops, because the height of the first rebound in each research week is higher. Moreover, the stabilizing of the rebound height in all research weeks occurs already after the second drop, which shows that the contact surface area quickly increases. In the fifth week apples partly rotted. Hence in figure 6 the fifth week marked by the dotted line, was not taken into consideration in the final results analysis

The influence of research time limit on bruise resistance

The next stage of the analysis was describing the bruise resistance and determining the influence of the research time limit on its variability. The comparison of the measurements results for the apples directly after the harvest and after the four-month storage period was carried out. The bruise energy is directly proportional and the bruise volume inversely proportional to the bruise resistance. The average bruise volume value did not change significantly during the tests in the consecutive research weeks. In case when the bruise volume is subject to small changes, variability of the bruise energy determines the changes of bruise resistance. In case of the apples directly after the harvest the bruise energy decreases with the storage time, hence the bruise resistance also decreases.

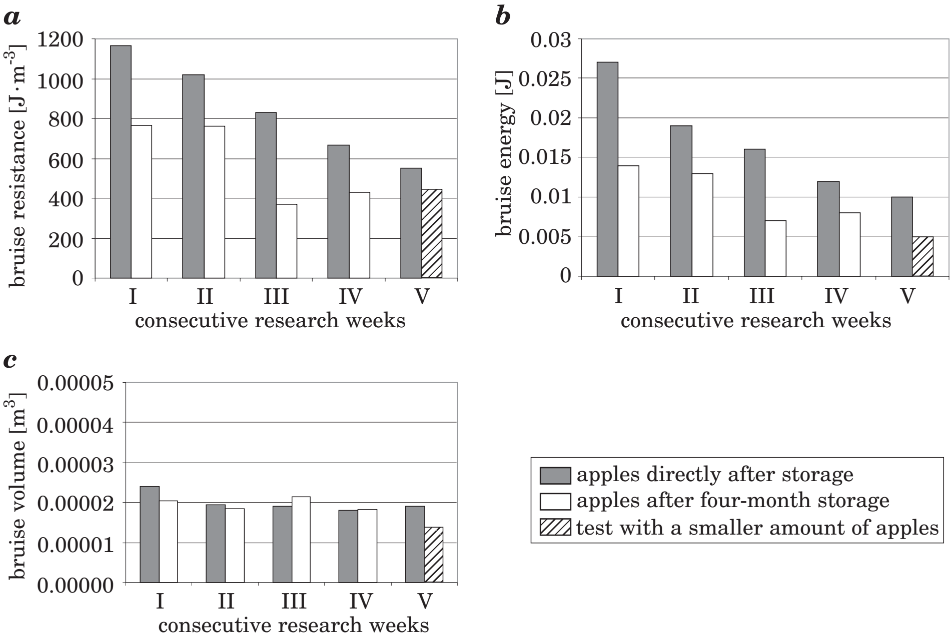

Fig. 7. Comparison of the average values: *a* – bruise resistance, *b* – bruise energy, *c* – bruise volume in the consecutive weeks for two research time limits

Figure 7 shows the average values of the bruise resistance and its components in separate research weeks for the apples directly after the harvest and after the four-month storage. In each graph (Fig. 7*a, b* and *c*) the fifth week in case of the apples after the four-month storage was filled with a pattern. In this way the trial with a smaller amount of the tested apples was marked. Figure 7*c* confirms the independence of the bruise volume from the length of the storage period and from the research time limits.

Conclusions

1. The bruise resistance of the apples subjected to the four-week storage directly after the harvest decreased with time.

2. There was stated a small variability of the bruise volume in the consecutive weeks for two research time limits. Hence also the main factor of the bruise resistance variability is the bruise energy.

3. The analysis of characteristic points location allows for comparative estimation of bruise stabilization phenomenon course for different apple varieties.

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