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DISTRIBUTION OF SURFACE PRESSURE OF AVOCADO FRUIT AT IMPACT LOADS

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ABSTRACT

The paper presents the results of measurements of surface pressure of Fuerte *avocado with the use of Tekscan system in impact loading conditions were presented. Contour lines of thrusts for two variants of loading which differ with speed and energy in the moment of crash were determined. Average values measured during the test were determined and statistical analysis was carried out for them. It was determined that the increase of speed and energy results in the increase of value of the maximum surface pressure but does not influence significantly their distribution on the resistance surface. It was proved that in the central area of contact mainly elastic strains appeared at the lack of plastic strains of tissue.*

Avocado fruit (Polish name: *smaczliwka*) comes from the Central America from Mexico. In the South America it has been known for thousand years. Avocado was brought to Europe by conquistadors, where it has become commonly available in the sixties of the 20th century. Presently, avocado is cultivated at the industrial scale mainly in the USA, Mexico, Brasil, Indonesia, New Zealand, Israel and the Republic of South Africa. In Poland in recent years import of avocado fruit has increased few dozens times.

Avocado during transshipment, transport, sorting and other treatments indispensable for obtaining the final product are subject to various static, dynamic and impact loads. Impact loads may mainly be a result of bruises which cause losses for entrepreneurs. Avocado is transported as non-ripen which considerably increases its resistance to mechanical damage. However, during supply of avocado directly to the final consignee, fruit must have proper degree of ripeness. Edward A. Baryeh (2000) when conducting research on the impact of the ripeness degree of avocado on resistance to bruises with the use of a penetrator determined that after 15 days from the moment of harvesting fruit, force necessary to place a penetrator by 5 mm was four times reduced.

At impact loads biological material behaves like material of elastic nature. Liquid and air which fill in inter cell spaces have no time to move to another regions with lower load (Gołacki, 2008). It causes exceed of cells strength and release of stresses in the form of crashes and damages to tissue. At low speed of load, biological material proves visco-elastic properties. In the initial stage of load after displacing gases and filling cell spaces, the process of migration of liquid takes place which causes strains of cell walls (Blachowec, 1985). A type of material strengthening is formed, which results from transferring loads by plant tissue components of higher strength, that is cell walls (Konstankiwicz et al., 1996; 1998; Lippert, 1995). As a result this type of load enables achievement of higher values of breaking stresses than at impact loads.

On account of avocado shape, analysis of contact loads may be one of the parameters which allow determination of resistance of mechanical damage. Contact issues referred to biological materials have been well described for apples at quasi-static loads. The most frequent is research, which tend to indicate changes of the surface area of apple contact with a working element of a testing machine influenced by external forces (Herold et al., 2001; Rabelo et al., 2001; Lewis et al., 2008). Acican (2007) carried out interesting research on apples at dynamic loads. Van Zeebroeck (2003) carried out investigation on apples with the use of a device which used the principle of a pendulum and executed discrete models of final elements which allow determination of the impact of transport conditions on the losses caused by damage to apples (Van Zeebroeck, 2007).

Frequently Hertz formulas are used for determination of surface pressure, however, they do not provide satisfying effects. On account of mechanical development of modelling methods which allow, to a higher extent, including properties which are characteristic for biological materials, determination of surface thrusts may constitute a basis for carrying out experimental verification of developed models (Stopa, 2011).

The objective of the research

The objective of the research was to determine contour layers and distribution of surface pressure of *Fuerte* avocado fruit by means of experiment in conditions of impact loads for two various speeds and energy of the impact.

Methodology and object of the research

The measurements were taken in the Department of Agricultural Engineering of the University of Life Sciences in Wrocław. A test rigs operating with the use of free pendulum principle equipped with a foil sensor of *Tekscan* system was used for research.

Carefully selected avocado fruit of Fuerte cultivar from plantations located in the Central America were designated for tests. Tests were carried out for fruit directly from a fruit store. The selected fruit during measurements were stored in a cool room in temperature approx. 3°C and air humidity at the level of 90-95%. They attempted to select fruit of a similar shape and weight (mass approx. of 210 g) and the same relation of height and diameter of $h/\phi = 0.5$. Geometric and strength dimensions of the research object were presented in table 1.

Test research position (fig. 1) was built of a rigid frame, the bottom fragment of which was made of a resistance flat surface. Structure of a frame allowed elimination of an effect of vibrations in the moment of impact. Impact load was performed with the use of a free pendulum mechanism. The research position allowed speed and impact energy control through change of the initial angle of location of the pendulum arm.

Table 1
Geometrical dimensions and strength properties of avocado fruit

Fruit mass m_o (g)	Stone mass m_p (g)	Fruit diameter φ (mm)	Fruit height h (mm)	Module of pulp elasticity Em (MPa)	Module of stone elasticity Ep (MPa)
210	50	70	140	0.98	695

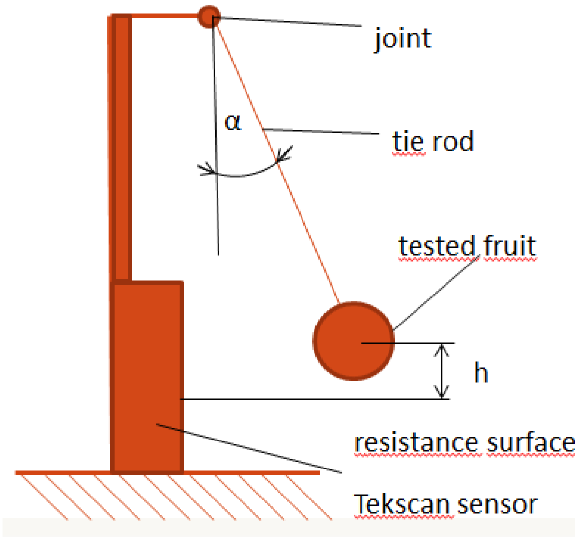


Figure 1. Measurement stand for impact research

A sensor used in tests had working surface with dimensions of 71.1x71.1 mm and average density of sensors which was 3.9 cm^{-2} (Table 2). Along with proper software it enabled collection of data with frequency reaching approx. 5000Hz.

Table 2
Technical data of a foil sensor

Sensor dimensions		Lengthwise direction		Crosswise direction		Number of sensors (items)	Density of sensors ($item \cdot cm^{-2}$)
Length (mm)	Width (mm)	Spacing (mm)	Number (items)	Spacing (mm)	Number (items)		
71.1	71.1	5.1	14	5.1	14	196	3.9

Source: www.tekscan.com

Test of impact load of avocado fruit was carried out for two different variants of test parameters (Table 3), which were obtained through the change of angle α of inclination of a test rigs pendulum arm. The change of impact from v=1.4 $m \cdot s^{-1}$ do v=2.0 4$m \cdot s^{-1}$ and energy of impact from E=0.5J to E=1.0J was obtained through the change of angle α from α=30 degrees to α=45. Ten repeats for each variant of load was carried out and statistical analysis for the maximum values of surface pressure were carried out.

Table 3
Exemplary test parameters

Variants	Mass m (kg)	Height Height (m)	Speed v ($m\cdot s^{-1}$)	Energy E (J)	Angle α (°)
1st variant	0.5	0.1	1.4	0.5	30°
2nd variant	0.5	0.2	2.0	1.0	45°

Results of measurements were subjected to statistical treatment with the use of Statistica software. 60 observations were analysed out of which 30 was for speed and energy of impact. For each value of particular properties a mean value of standard deviation and 95% confidence interval for a mean value were calculated. Table 3 and 4 present exemplary results of statistical analysis, which include determination of surface thrusts for two speeds and energy of impact.

Errors related to the shape of samples, measurement of the pressure force and determination of the contact surface constituted a part of total error of experimental determination of surface pressure. On account of very careful preparation of samples for research, the error of shape as a systematic error may be omitted. Measurement of force, measurement of the surface area of contact and the value of surface pressure was determined with the use of Tekscan system of the following parameters: system precision <±4%, blinearity error<±3%, repeatability of results<±3.5%, hysteresis<±4.5% and drifting: <5%.

Research results and their analysis

A pendulum device after setting an inclination angle of an arm, was moved by releasing a lock mounted to the structure of test rigs. Avocado fruit upon hitting an obstacle was bounced several times to complete stop. Figure 2 presents subsequent impulses calibrated in surface pressure as time function. In case of the 1st variant of the impact parameters (table 1) to the total stop of a pendulum, 6 impacts of avocado at a resistance surface were indispensable. Values of maximum surface pressure decreased in subsequent impulses from p=0.48 MPa to p=0.11 MPa, whereas the force of impact was changing within F=141 N to F=4 N.

Each impulse of force was composed of two characteristic stages which divide an impulse into two parts (figure 3a). The first stage including 4.75 ms was characterised with violent increase of impact force and then upon reaching the maximum value with an explicit decrease but without the contact of avocado fruit with the surface of a resistance surface. The second stage of impulse lasting 6.41 ms started from the increase of the impact force from the minimum value achieved at the end of the 1st stage to the maximum value not higher than the maximum value obtained in the 1st stage. The final stage of force impulse was a gradual decrease of the impact force to the loss of contact of avocado with a resistance surface. Similarly, values of surface thrusts change during a single force impulse (fig. 3b). However, on account of deformation of avocado fruit pulp and thus the change of the surface of contact of a fruit with a resistance surface, the course of pressure changes is milder. Values of pressures obtained in the second stage of an impulse are clearly lower than in the first one.

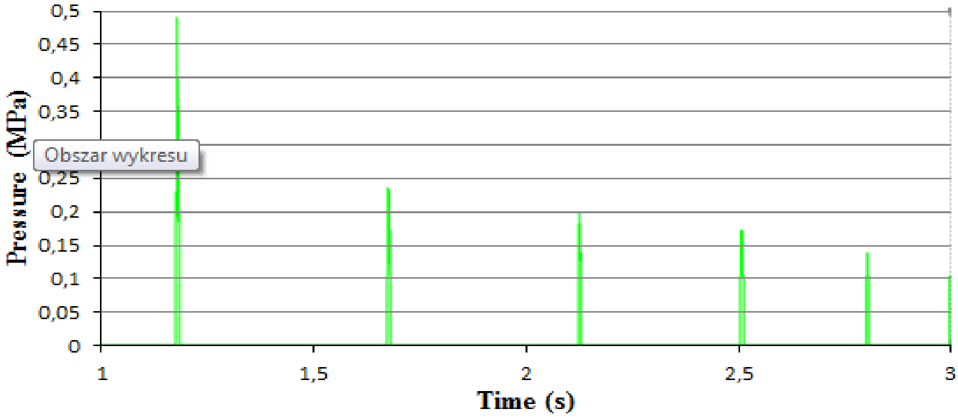
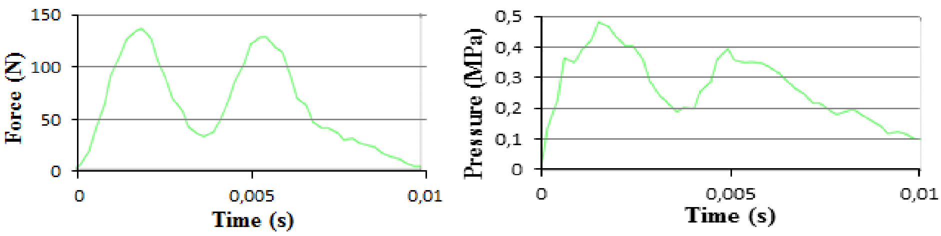


Figure 2. Subsequent impulses of surface pressure as the time function (1st variant)



a) impulse of force b) impulse of surface thrusts

Figure 3a and b. Impulse of force and surface pressure as a function of time (1st variant)

Total time of contact of fruit with a resistance surface from the moment of commencement of contact to its end during the first impulse was 11.16ms. Such behaviour of avocado fruit during the impact may be explained by interaction of a stone, the mass of which is approx. 25% of the mass of the whole fruit and the module of elasticity is 700 times higher than the module of the pulp elasticity (table 1).

When analysing contour layers of surface thrusts (figure 4) for the 1st variant of load (table 3) in the first stage of impact (after 2.24 ms from the beginning of contact), one may report that the maximum values of surface thrusts are in the central zone of contact and decrease when getting closer to border areas of contact. In the cross-section distribution of surface thrusts has a shape of even curve with the maximum in the central point of contact of avocado fruit with a bumper. The maximum surface pressure achieve value to p= 0.699 MPa and their mean is p=0.449 MPa (Table 4).

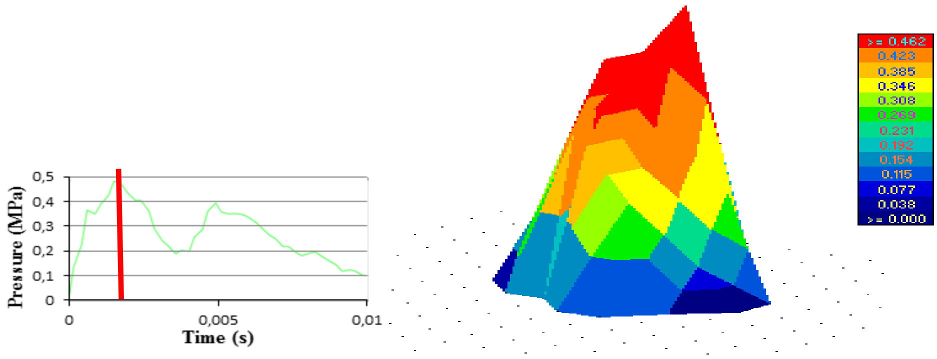


Figure 4. Contour layers of surface pressure – the first variant of load (Δt =2.24ms)

In the bounce phase for the first stage of force impulses (figure 5) after 4.51 ms from the beginning of contact the image of surface pressures in the contact area has not significantly changed. Values of surface thrusts and the contact surface but the system of contour layers has not changed. The maximum value of surface pressure in the final bounce phase was p=0.205 MPa.

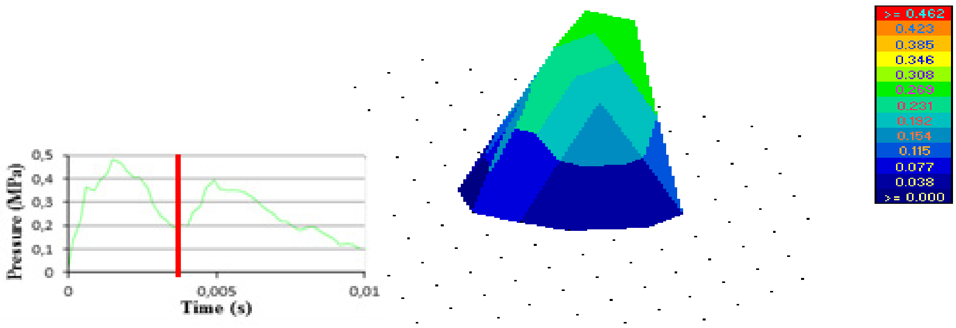


Figure 5. Contour layers of surface pressure – the first variant of load (Δt =4.51ms)

In the second stage of impact force impulse, the system of contour layers of surface pressure (fig. 6) has a shape similar to the system of the first stage of force impulse. Maximum values are in the central contact zone but both force and value of pressures were reduced. The maximum value of surface thrusts on this stage of force impulse operation was p=0.595 MPa, at the impact load of F=131 N.

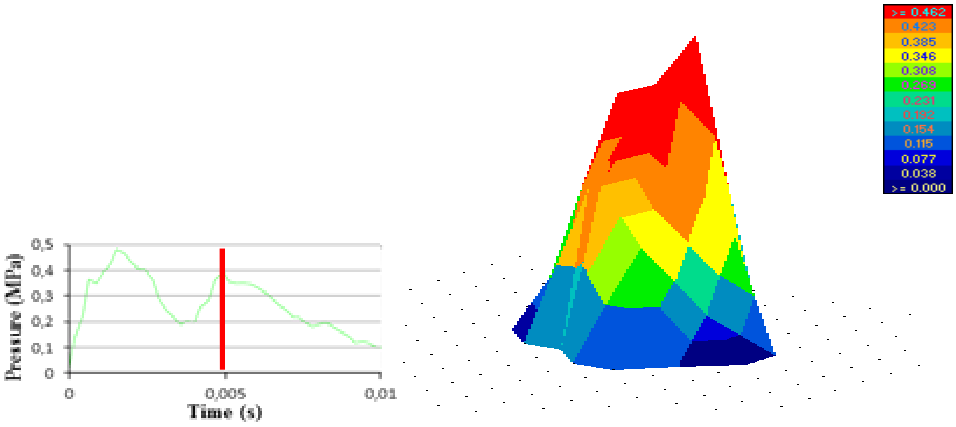


Figure 6. Contour layers of surface pressure – the first variant of load (Δt =6.41ms)

Such distribution of pressures may prove small values of plastic strains of the pulp tissue in the zone with the highest loads and prevailing elastic strains which cause avocado fruit bounce on a resistance surface. Majority of cells which are in the contact zone participate in returning elastic energy collected during a bump.

Table 5 presents mean values of parameters which are the object of measurements during tests which were performed along with the statistical analysis carried out for a test consisting in 10 repeats for the whole force impulse.

Table 4
Test results – first impulse (v=2 m·s^{-1}, E=1.0 J)

Factor	Value	
	stage 1	stage 2
Maximum pressure p_{max} (Mpa)	0.699	0.595
Mean pressure p_{max} (Mpa)	0.449	0.358
Force F (N)	139	131
Time of contact Δt (ms)	4.75	6.41
Impulse of force (N·*s*)	1.506	
Impulse of pressure (MPa·*s*)	0.004497	

Table 5
Test results statistical analysis – first impulse ($v=2\ m{\cdot}s^{-1}$, $E=1{,}0\ J$)

Factor	N	Mean value	Standard deviation	95% confidence interval	
Maximum pressure p_{max} (Mpa)	10	0.403	0.0336	0.3884	0.4356
Force F (N)	10	135	6.50	128.97	144.03
Time of contact Δt (ms)	10	11.16	0.12	10.32	12.12

At higher values of speed and energy in the moment of impact planned during tests (2nd variant of load – table 3) the image of surface pressures in the contact zone does not significantly change. A single impulse for the 2nd variant of load in the initial phase of impact had a similar course for the 1st variant. Very quickly because in time approx. of 2 ms a maximum value of surface pressure was achieved (fig. 7). Two stages of force impulse are visible as in the 1st variant.

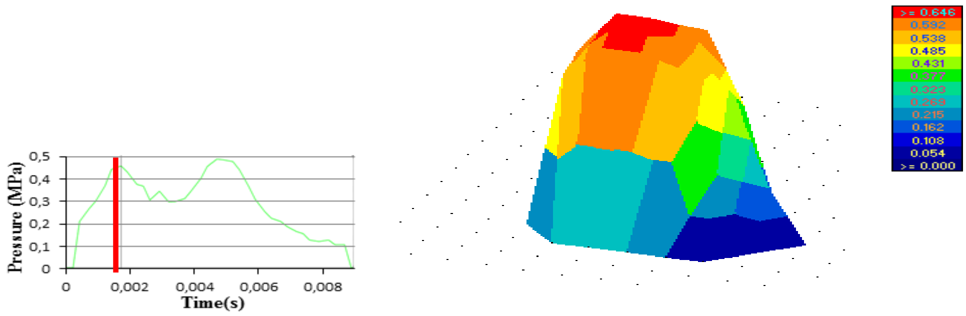


Figure 7. Contour layers of surface pressure – the second variant of load (Δt =1.77ms)

In the initial moment of impact (after 1.77 ms) a contact of avocado with the resistance surface had a point nature (fig. 7). At a small surface area of contact, the maximum values of surface pressure (p=0.612 MPa) were in the area of central zone but average value of pressure was p=0.462 MPa

As a result of fast operation of big pressure force on a small area an increase of pressure of cell liquids in the contact zone took place, which at lack of cell destruction led to elastic strains. Accumulated elastic strain resulted in bouncing avocado on a resistance surface (fig. 8), which was recorded as decrease of the values of maximum surface pressure to the level of p=0.385MPa.

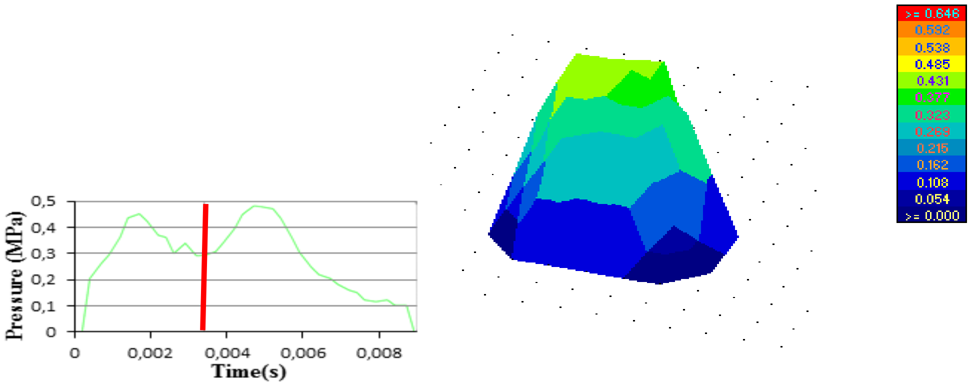


Figure 8. Contour layers of surface pressure – the second variant of load (Δt =3.34 ms)

Then, most probably as a result of inertial force of stiff stone the increase of surface pressures took place reaching the value of p=0.656MPa (fig. 11) and a gradual decrease to the moment avocado lost contact with the resistance surface.

The described mechanism of phenomena which take place during the impact of avocado fruit with the resistance surface did not lead to destruction of the pulp tissue and formation of elastic strains. The maximum values of surface pressure appeared always near the central contact point and disappeared at the border of the contact area in places, where new batches of cells entered the contact zone.

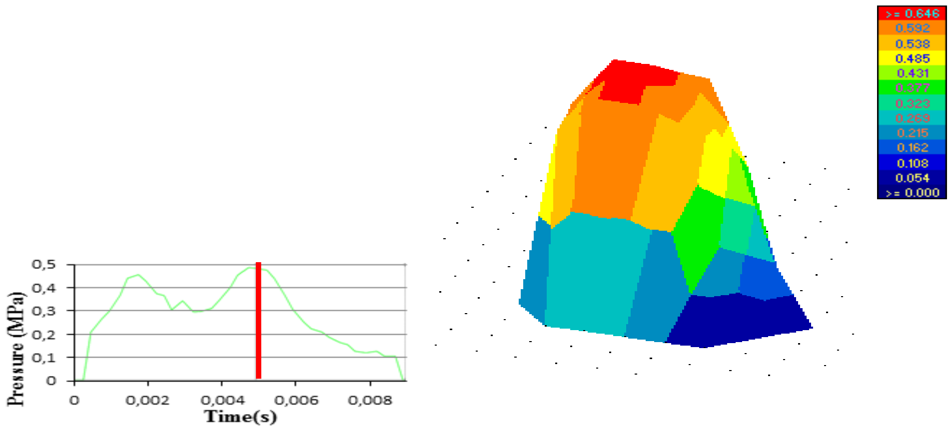


Figure 11. Contour layers of surface pressure – the second variant of load (Δt =4.99 ms)

Average values of parameters measured during the test at the 2nd variant of load (table 3) along with the statistical analysis carried out for 10 repeats was presented in table 7. The fact that along with the increase of force in the impact moment for the 2nd variant of load towards the 1st variant, surface thrusts were proportionally increased, should be mentioned. Contact time changed from 11.16 ms to 8.8 ms. It proves strain nature of the impact test which was carried out.

The impulse of force calculated as a quotient of average force and time of operation on avocado fruit and analogically the impulse of surface pressure calculated as a quotient of average pressure and time of its operation is an interesting parameter which describes the impact test. As long as the impulse of force for both variants of load increased almost by 19% the impulse of surface pressures increased only by over 7%.

Table 6
Test results – first impulse ($v=4\ m{\cdot}s^{-1}$, $E=6.7$ J)

Factor	Value	
	stage 1	stage 2
Maximum pressure p_{max} (Mpa)	0.612	0.656
Mean pressure p_{max} (Mpa)	0.462	0.490
Force F (N)	179	227
Time of contact Δt (ms)	1.77	4.99
Impulse of force (N·*s*)	1.786	
Impulse of pressures (MPa·*s*)	0.00418	

Table 7
Test results - first impulse ($v=4\ m{\cdot}s^{-1}$, $E=6,7$ J)

Factor	N	Mean value	Standard deviation	95% confidence interval	
Mean pressure p_{max} (Mpa)	10	0.476	0.0336	0.4584	0.4956
Force F (N)	10	203	4.50	192.97	214.03
Time of contact Δt (ms)	10	8.8	0.12	8.52	10.12

Conclusions

1. Contour layers of surface pressure slightly depend on the energy of avocado fruit impact. Mean values of maximum surface pressure increase from p=0.403 MPa at E=0.5J to p=0.476 MPa at E=1.0J.
2. Mass of a stone significantly influences distribution of surface pressure during a single impulse.
3. Maximum values of surface pressure are distributed close to the central point of contact of avocado fruit with impediment both in the phase of entering the contact as well as in the stage of bounce. It proves low loss of elastic properties by avocado pulp.

4. The increase of impact energy in the researched scope of loads causes shortening of the contact time of avocado with an impediment.
5. Research results may serve as verification of discreet models of processes related to harvesting, transport and storage of apples.

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Avocado, grupa Itum, pozyskano ze stronu:www.itum.com.pl

ROZKŁADY NACISKÓW POWIERZCHNIOWYCH OWOCÓW AVOCADO PRZY OBCIĄŻENIACH UDAROWYCH

Streszczenie. W pracy przedstawiono wyniki pomiarów nacisków powierzchniowych avocado odmiany *Fuerte* przy pomocy systemu Tekscan w warunkach obciążeń udarowych. Wyznaczono warstwice nacisków dla dwóch wariantów obciążenia różniących się prędkością i energią w momencie zderzenia. Wyznaczono średnie wartości wielkości mierzonych podczas testu i przeprowadzono dla nich analizę statystyczną. Ustalono, że wzrost prędkości i energii zderzenia powoduje zwiększenie wartości maksymalnych nacisków powierzchniowych, ale nie wpływa w istotny sposób na ich rozkład na powierzchni oporowej. Wykazano, że w centralnej strefie styku występowały głównie odkształcenie sprężyste przy braku odkształceń plastycznych tkanki.

Słowa kluczowe: naciski powierzchniowe, avocado, obciążanie udarowe