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RESPONSE OF THE POTATO TUBERS TO IMPACT LOADING

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Abstract

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The response of tubers of nine varieties of potatoes to the bar impact have been evaluated. The proposed method enables to obtain force – time record. The response function is represented by the time history of the surface displacement. This function has been recorded using laser vibrometer technique. The main features of the force and displacement function have been found both in the time and frequency domain. It has been found that given method can be used for the detection of the potato tubers damage origin as well as for the differentiation among different varieties of the potatoes. There is also a chance to evaluate the main mechanical characteristics of the potato tubers by non – destructive way.

potato tuber, impact loading, frequency analysis, tuber damage

The mechanical properties and rheological behaviour of raw potato tubers have been widely examined for both scientific and technological purposes. The standard parameters and conditions of determination are, however, not commonly accepted. Various methods, such as uniaxial compression (Thybo and Van Den Berg, 2002; Blahovec and Esmir, 2001), tensile test (Verlinden *et al.*, 2000), penetration tests (Anzaldúa-Morales *et al.*, 1992), puncture test (Ranganna *et al.*, 1998) and numerous variants of small deformation tests (Laza *et al.*, 2001) have been proposed for the evaluation of the mechanical/textural parameters of raw and treated potato tubers. One of the methods is dynamics excitation and response analysis.

This response technique is a fast, nondestructive measurement of firmness, where the food excited by being struck with a probe and the frequency spectrum from the recorded sound is obtained. This technique was used to detect surface cracks in eggshells or voids in watermelons (Cho et al., 2000; Diezma-Iglesias et al., 2004). Furthermore, this methodology has been applied on fruits such as peaches, apples and pears, in order to quantify changes in firmness during ripening (De Belie et al., 2000a, 2000b; Diezma-Iglesias et al., 2006; Zude et al., 2006). Some impact response parameters such as maximum force, maximum deformation and duration of impact have shown to be closely related to firmness, and therefore to ripeness during the post-harvest period (García et al. 1988). The objective of this paper was to study the behaviour of the tubers under impact of a bar. This behaviour was characterized by the time history of the tuber surface displacement.

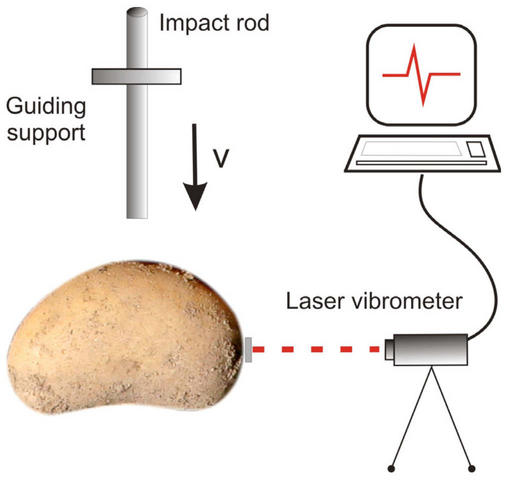
MATERIALS AND METHODS

Nine potato cultivars were examined: Jitka, Karin, Judita, Magda, Princess, Red Anna, Kerkovsky Rohlicek, Rosara and Velox.

The used experimental set-up is shown in Fig. 1. It consists of three major components: they are the potato tuber support, the loading device and the response-measuring device.

1. The tuber support used is a cube of soft polyurethane foam. The stiffness of this foam is significantly lower than the tuber stiffness therefore there is very little influence of this foam on the dynamic behaviour of the tuber.
2. A bar of the circular cross - section with strain gauges (semi conducting, 3 mm in length) is used as a loading device. The bar is made from aluminium alloy. Its length is 200 mm, diameter is 6 mm. The bar is allowed to fall freely from a pre-

selected height. The instrumentation of the bar by the strain gauges enables to record time history of the force at the area of bar - tuber contact.
3. The response of the tuber to the impact loading described above has been measured using the laser vibrometer. This device enables to obtain the time history of the tuber surface displacement.



1: *Schematic of the impact loading of the potato tuber*

The photo of the experimental device is presented in the Fig. 2.

The tubers have been impacted on the equator. The height of the bar fall has been increased up to value at which the tuber damage has been observed. The displacement has been recorded on the equator of the tuber. The displacement has been measured in direction normal to the tuber surface.

RESULTS AND DISCUSSION

In the Fig. 3 an experimental records of the impact force - time are shown. The damage of the tuber occurs at the height h = 690 mm. The impact velocity 3.68 m.s^{-1} corresponds to this height of the bar fall. The damage of the tuber is not too severe – see photo in the Fig. 4.

The shape of the force F versus time t curve can be characterized by three basic parameters:

- The maximum force during the impact (F_m),
- The duration of the F(t) pulse (λ),
- The time spent until the maximum force is reached (t_I).

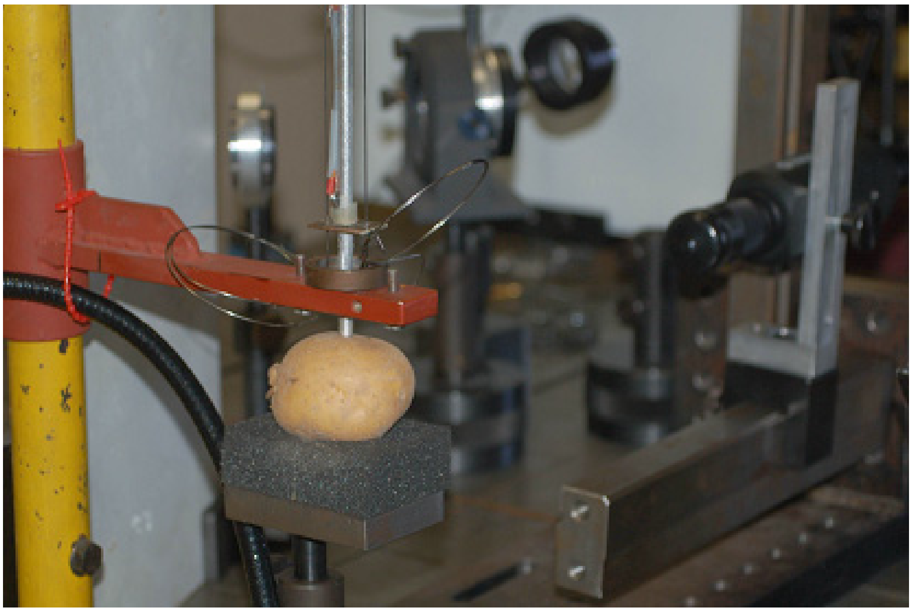
In the Fig. 5 the values of the maximum of the force are displayed. This force increases with the height of the bar fall, i.e. with the bar impact velocity, as expected. The values of this force are different for the different varieties of the potatoes.

The time spent until the maximum force is reached decreases with the impact velocity – see Fig. 6.

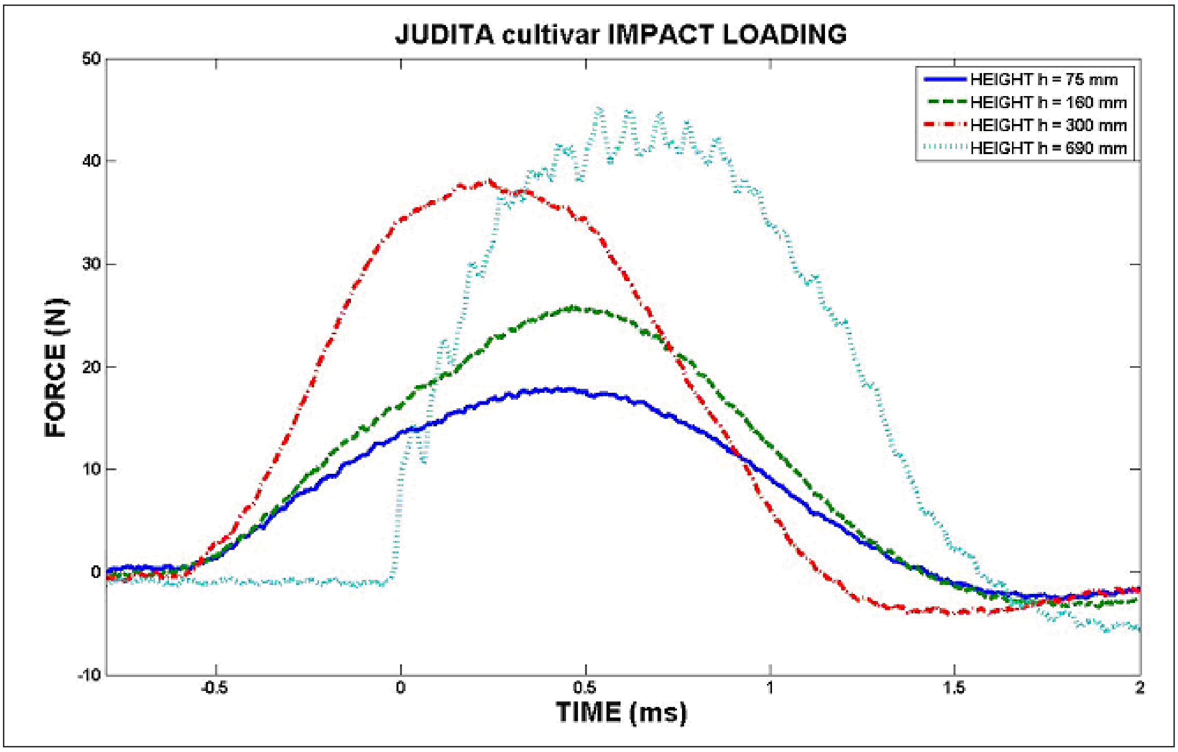
Duration of the force pulse increases with the bar impact velocity up to its critical value at which the potato tuber damage starts. The tuber damage is connected with the decrease of the force pulse duration – see Fig. 7.

The response functions are represented by the time histories of the tuber surface displacements. Example of these functions is shown in the Fig. 8.

The first part of this curve corresponds to the propagation of the pressure-stress pulse from the point of the bar impact. Its amplitude increases with the impact velocity of the bar. This part is followed by a release part (tensile pulse). The response functions of the remaining potatoes tubers exhibit the same qualitative features.



2: *Experimental device*



3: *Experimental records of the impact force vs. time*

4: *Tuber damage during the bar impact (Judita cultivar)*

The response of the potato tuber can be also described in the frequency domain. This procedure is based on the Fourier transform technique – see e.g. Stein and Shakarchi (2003) for a review.

For a continuous function of one variable f(t), the Fourier Transform F(f) is be defined as:

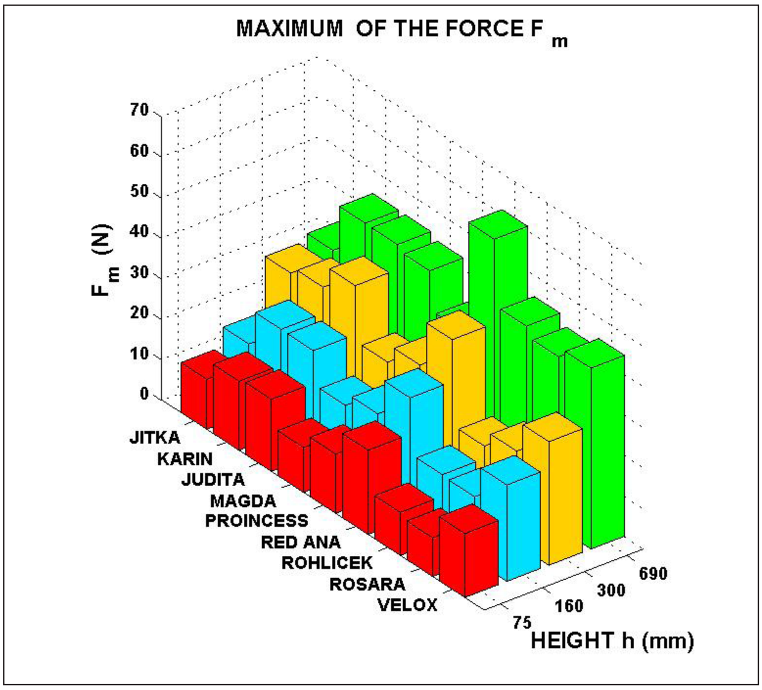
$$F(\omega) = \int_{-\infty}^{+\infty} f(t)\, e^{-i\omega t} dt$$

And the inverse transform as

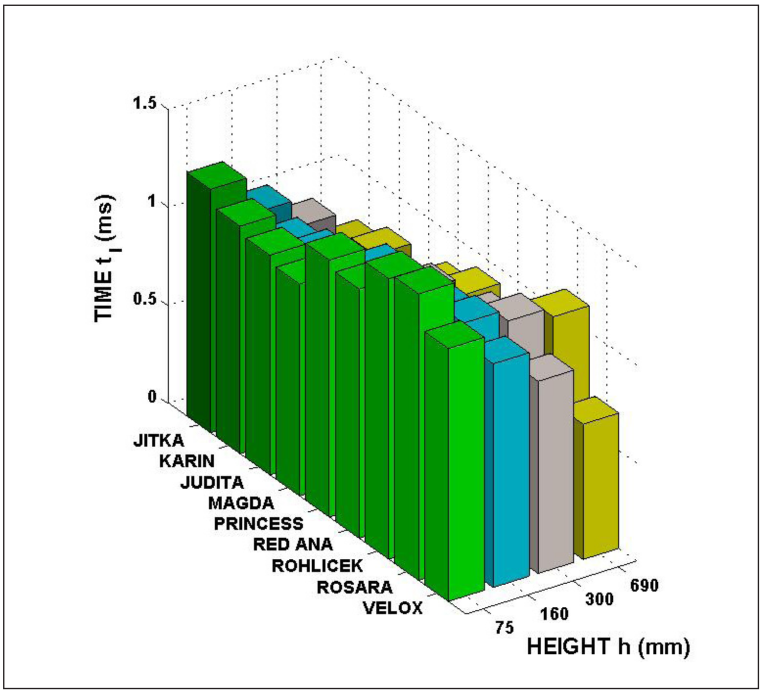
$$f(\omega) = \int_{-\infty}^{+\infty} F(t)\, e^{i\omega t} d\omega,$$

where F is the spectral function and ω is the angular frequency.

The same procedure can be used for the Fourier transform of a series x(k) with N samples. This procedure is termed as the discrete Fourier Transform



5: *The maximum of the impact force*



6: *Time at which the force maximum is reached*

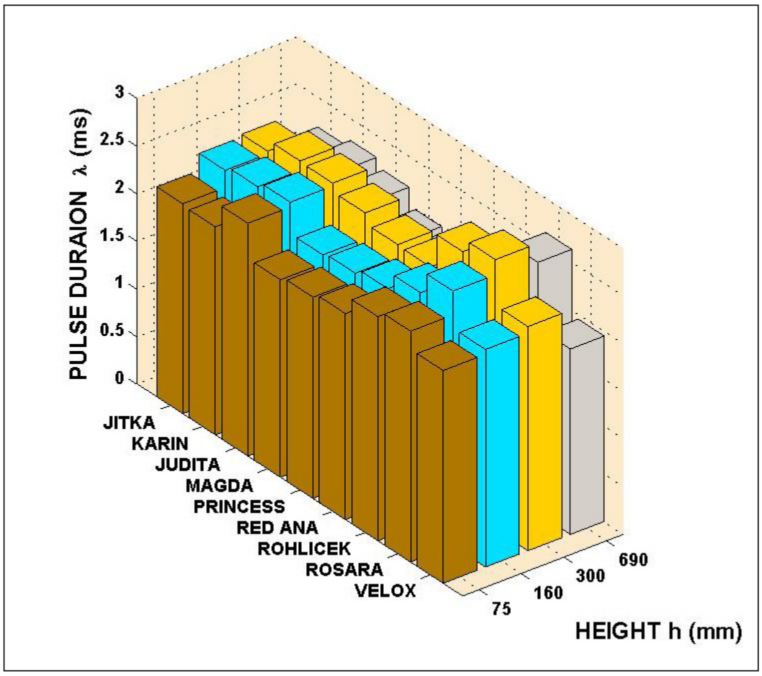
(DFT). A special kind of this transform is Fast Fourier Transform (FFT). This procedure is part of the most software packages dealing with the signal processing. The transform into the frequency domain will be a complex valued function, that is, with magnitude and phase:

$$F(\omega) = \mathrm{Re}(f) + i\mathrm{Im}(F)$$

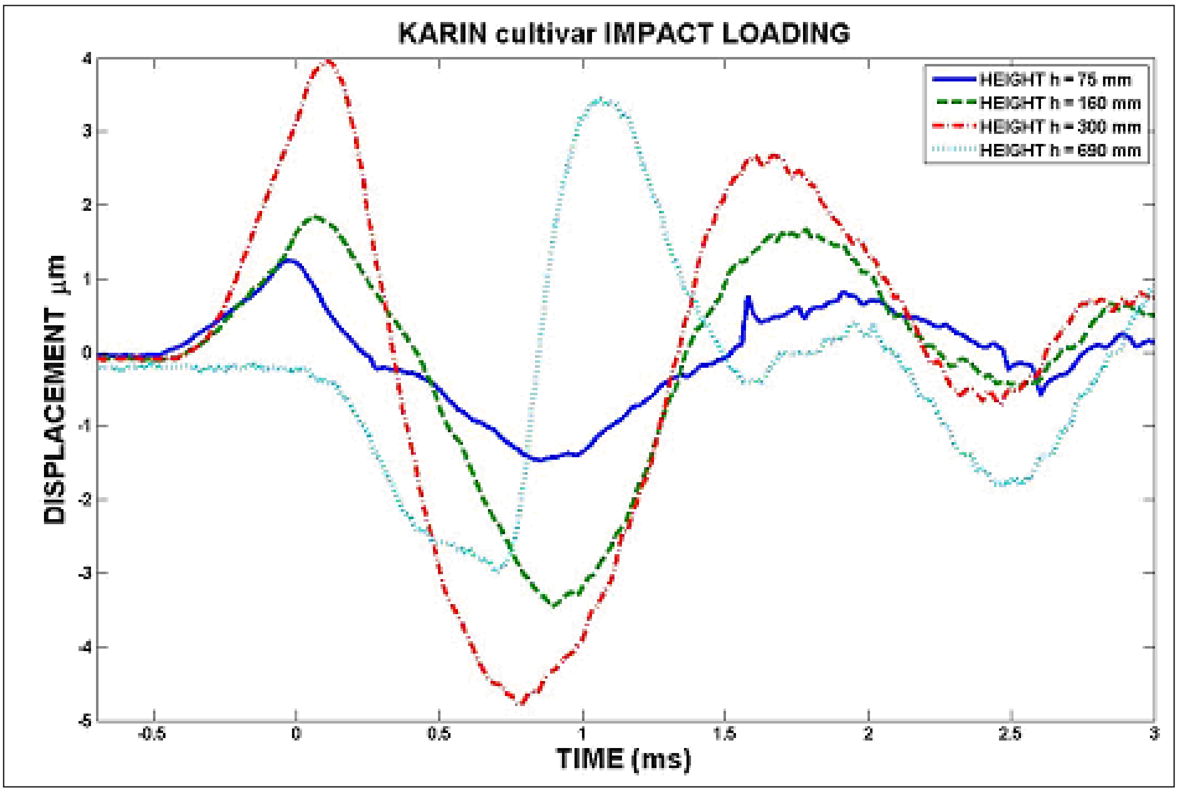
$$amplitude = \sqrt{\mathrm{Re}(F) + \mathrm{Im}(F)}$$

$$phase = \arctan\left[\frac{\mathrm{Im}(F)}{\mathrm{Re}(F)}\right]$$

In the Fig. 9 an example of the frequency dependence of the amplitude of the spectral function



7: *The time of the pulse F(t) duration*

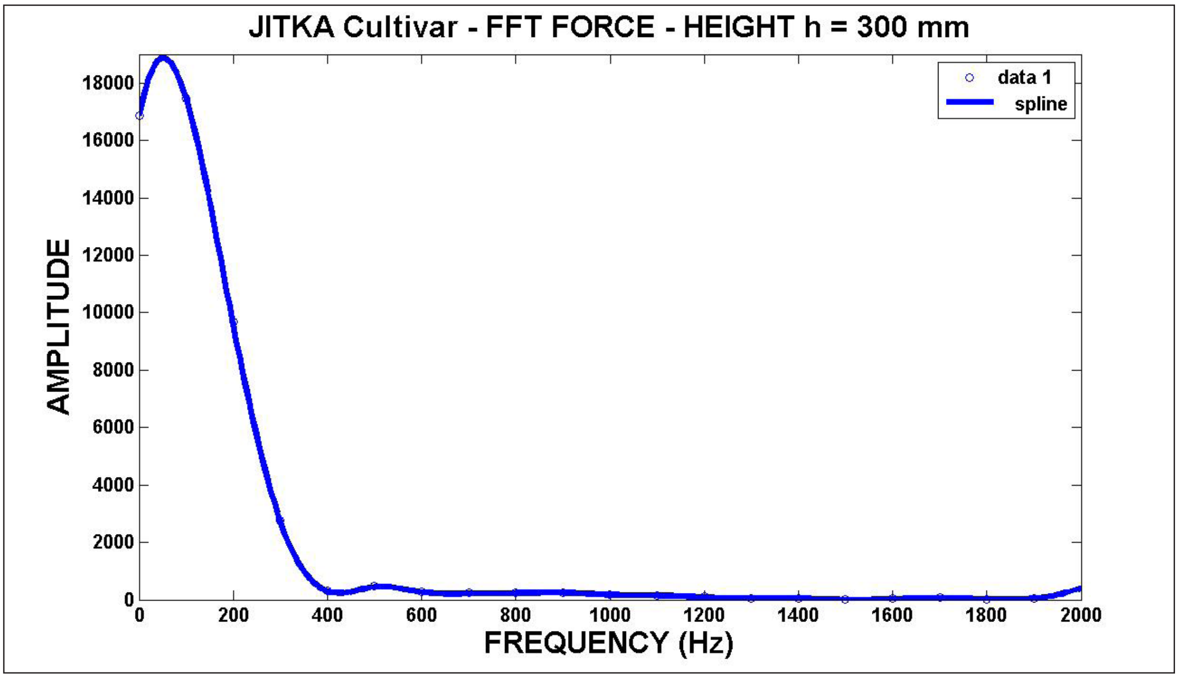


8: *Surface displacements versus time curves for the different bar impact velocities*

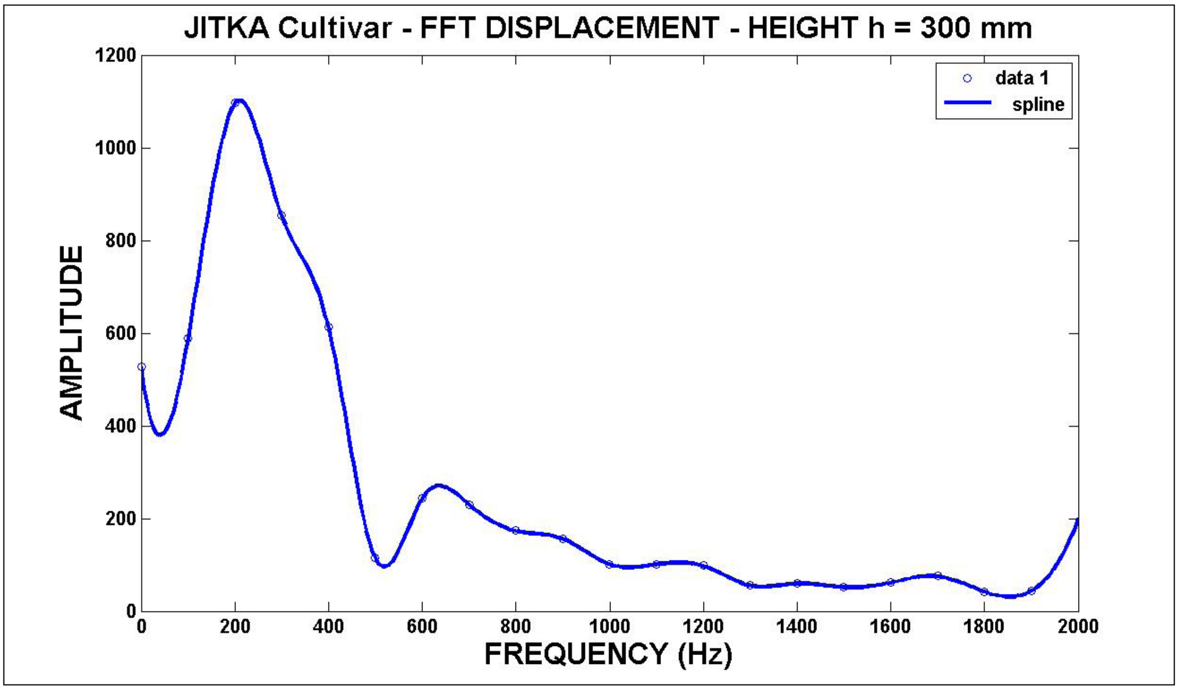
(force) is shown. One can see that the most significant are frequencies well below c. 2000 Hz.

Example of the amplitude obtained for the displacement is displayed in the Fig. 10.

The amplitude exhibits a maximum. The corresponding frequency is denoted as the dominant frequency. This frequency plays dominant role at the evaluation of the mechanical stiffness of many fruits and eggshell. Its value depends on the excitation intensity (i.e. on the height of the bar fall) and on the variety of potatoes. Values of these frequencies are plotted in the Fig. 11.



9: *Amplitude of the spectral function (force) versus frequency*



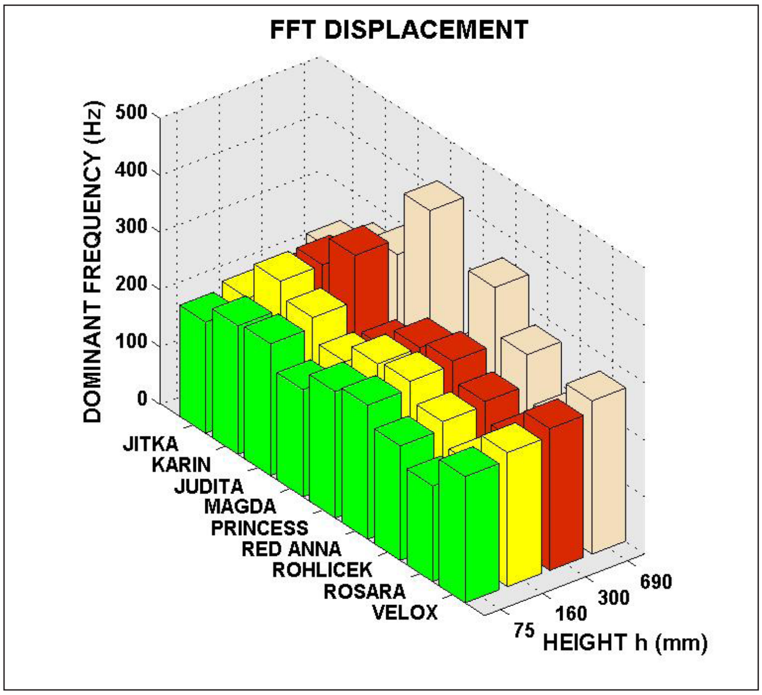
10: *Amplitude of the spectral function (displacement) versus frequency*

In order to describe the mechanical properties of the tested materials using the response functions, one must use some assumptions about material behaviour. The simplest model represents the linear elastic body. The real body, e.g. potato tuber, can be represented by single degree of freedom system (SDOF) as shown in Fig. 12.

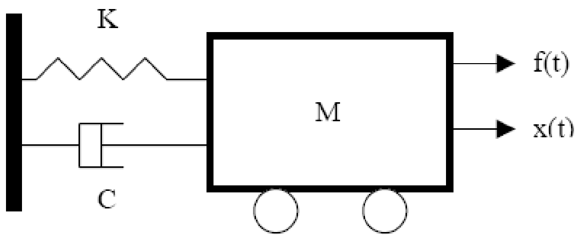
Mathematical representation of a SDOF system is expressed in equation:

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = f(t) \quad (1)$$

Where M = mass, C = damping, K = stiffness, f = external force, x = displacement



11: *Dominant frequencies of the tested potatoes tubers*



12: *Single degree of freedom system*

Transferring this time domain into frequency domain, Equation (1) becomes:

$$[-M\omega^2 + iC\omega + K]X(\omega) = F(\omega) \quad (2)$$

or

$$Z(\omega)X(\omega) = F(\omega) \quad (3)$$

The inverse of Equation (2) or (3) gives the frequency response function (FRF) of the system H(ω):

$$X(\omega) = H(\omega)F(\omega) \quad (4)$$

Equation (4) relates the system response $X(\omega)$ to the forcing function and the FRF can be defined as

$$H(\omega) = \frac{X(\omega)}{F(\omega)}$$

The frequency response function (sometimes called as transfer function) plays significant role in the extracting of the modal parameters of the tested body. The procedure can be found i.e. in Coucke et al. (2003).

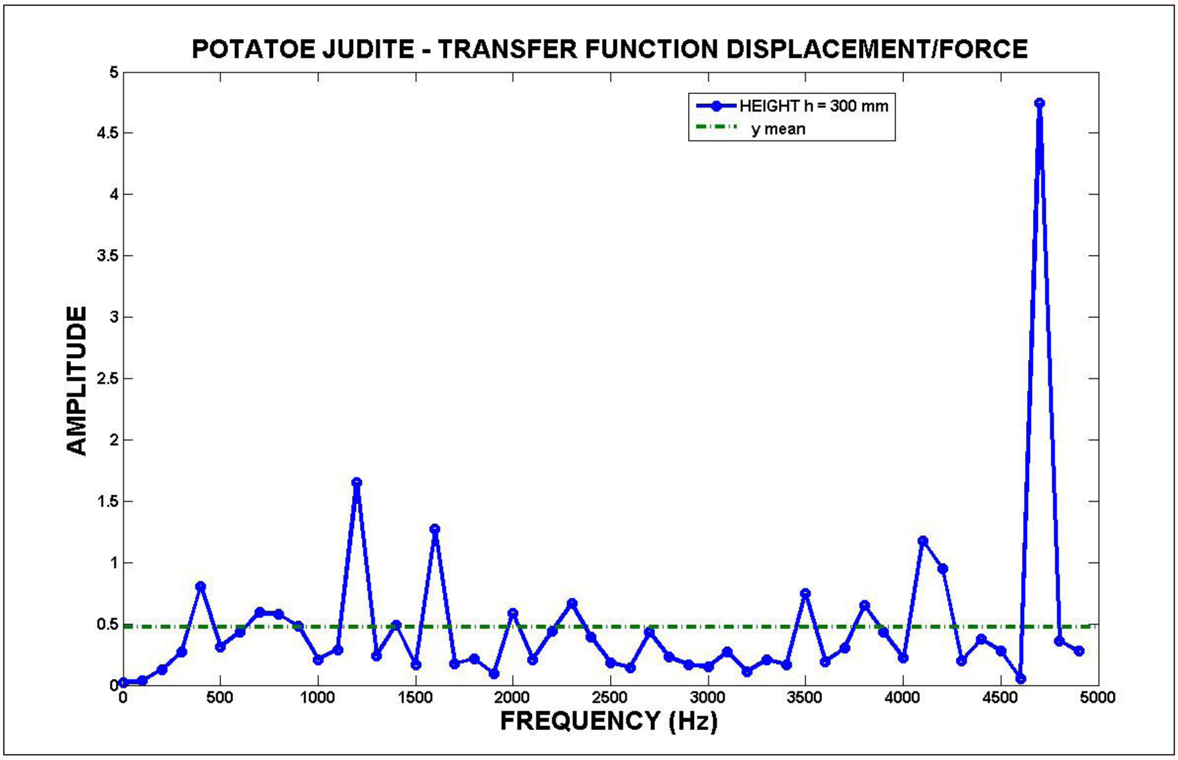
In this paper we limit the consideration on some qualitative features of this FRF function. In the Fig. 13 an example of the amplitude of the transfer function is shown.

The values of this amplitude lie below one with the exception of a limited number of frequencies. In the Fig. 14 the mean values of the amplitudes are plotted.

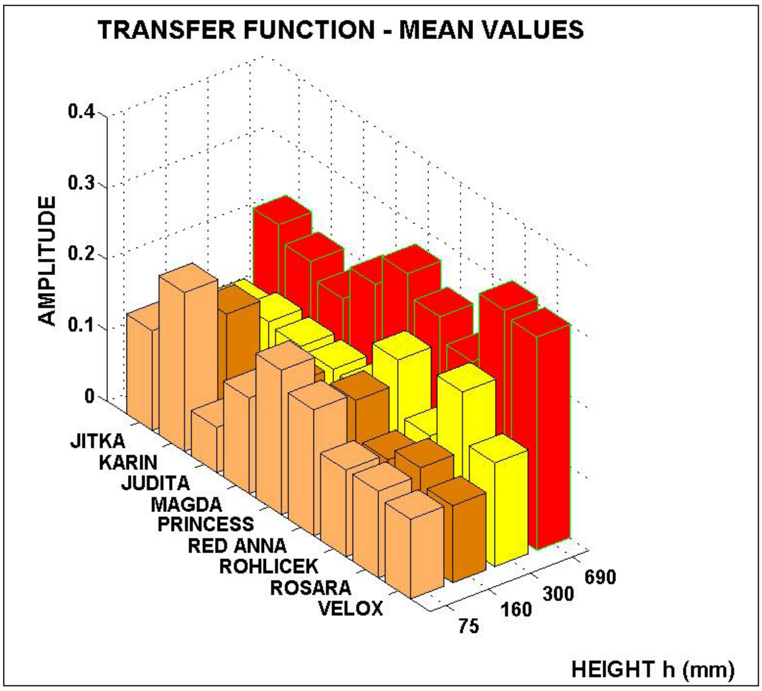
These mean values are probably typical for single varieties of the tested potatoes. Their dependence on the impact velocity of the bar is remarkable only for some varieties of potatoes. Some additional research is needed.

CONCLUSSIONS

In the given paper evaluation of potato tubers response to mechanical impact has been performed. Typical cultivar's differentiation of the response of potato tubers was found. The differences have been observed both in the time and frequency domain. The suggested experimental method enables to study the mechanical resistance of the potato tubers against the impact loading. It has been found that the damage of the tubers led to significant change in behaviour of the force - time function. Parameters of this function have been obtained. Response function, displacement versus time, exhibited main features corresponding to the surface wave propa-



13: *Amplitude of the transfer function*



14: *Mean amplitudes of the transfer function*

gation. The spectral function of the displacement exhibits a dominant frequency. It means there is a chance to use the obtained data for the evaluation of the mechanical properties of the potato tubers. The proposed method seems to be promising tool, how to distinguish between different varieties of the potatoes. The detection of the potato tubers damage is probably also possible. In order to verify these possibilities additional experiments are desirable.

SOUHRN

Odezva bramborových hlíz na rázové zatěžování

V dané práci jsou uvedeny pravděpodobně prvé výsledky studia odezvy devíti odrůd bramborových hlíz na rázové zatěžování dopadající tyče. Toto zatěžování je realizováno pomocí nově navržené experimentální metody, která umožňuje jak stanovení časového průběhu zatěžující síly, tak záznam časového průběhu posunutí, resp. i rychlosti posunutí povrchu hlízy. Jsou vyhodnoceny časové průběhy kontaktní síly. Ukazuje se. že parametry popisující tvar silového pulsu – tzn. maximální hodnota, doba jejího dosažení a celková doba trvání, jsou závislé jak na druhu bramborové hlízy, tak na rychlosti dopadu tyče. Je ukázán postup, který umožňuje stanovit sílu v momentě vzniku mechanického poškození bramborové hlízy. Odezva je popsána časovou závislostí výchylky povrchu bramborové hlízy, která byla získána pomocí laserového vibrometru. Výchylka povrchu vykazuje oscilační charakter a odpovídá šíření povrchové vlny napětí. Parametry těchto odezvových funkcí jsou rovněž závislé na rychlosti dopadu tyče a na odrůdě testované brambory. Byla rovněž provedena úvodní analýza odezvy ve frekvenční oblasti. Ukazuje se, že tato odezva je charakterizována určitým maximem, stejně jak v případě jiných produktů jako např. u různých druhů ovoce, u vaječných skořápek apod. U těchto materiálů je frekvence, při které dochází k maximu odezvové funkce, použitelná pro stanovení mechanické pevnosti. To naznačuje možnost použití dané metody pro nedestruktivní hodnocení mechanických vlastností bramborových hlíz. Ověření této možnosti vyžaduje další experimenty, což bude obsahem následujících prací. Byly stanoveny přenosové funkce, které popisují frekvenční odezvu. Jejich průměrné hodnoty opět závisí jak na rychlosti dopadu tyče, tak na odrůdě zkoumaných brambor. Celkově se ukazuje, že navržená experimentální metoda umožňuje detekovat vznik poškození bramborové hlízy a rozlišit jednotlivé druhy brambor z hlediska jejich mechanických vlastností.

bramborová hlíza, rázové zatěžování, frekvenční analýza, poškození hlízy

SUMMARY

A new experimental method based on the dynamic excitation and response analysis has been used to description of the mechanical behaviour of potatoes tubers. The nine cultivars of potatoes have been tested (Jitka, Karin, Judita, Magda, Princess, Red Anna, Kerkovsky Rohlicek, Rosara and Velox). The loading of the tubers has been performed by the impact of the free falling rod. The record of the force at the point of rod – potato tuber contact enables to evaluate the rupture force at a definite impact velocity. The force versus time functions exhibited the same qualitative features up to the tuber damage origin. The shape of the force pulse has been characterized by three parameters: maximum value of the force, time of the force maximum achieving and by the force pulse duration. The values of these parameters are dependent on the bar impact velocity. The parameters are also different for the different cultivars of the potatoes. The response of the tuber has been described by the time history of the tuber surface displacement. The displacement versus time functions exhibited a nearly sinusoidal shape typical for the surface wave propagation. Their parameters, e.g. maximum and minimum values have been also dependent on the bar impact velocity. The function mentioned above exhibited significant changes at the moment of the tuber damage origin. The response of the potato tuber to the impact loading has been also described in the frequency domain using the Fourier transform. This transform enables to substitute the function f(t) by a complex function dependent on the frequency. These functions have been evaluated both for the force - time pulse as well as for the displacement – time functions. The spectral functions corresponding to the surface displacement have exhibited a maximum. The corresponding frequency was denoted as the dominant frequency. This frequency plays dominant role at the evaluation of the mechanical stiffness of many fruits and eggshell. Its value depends on the excitation intensity (i.e. on the height of the bar fall) and on the variety of potatoes. There is a chance to use this frequency also for the description of the mechanical behaviour of the potatoes tubers. The frequency response functions (transfer functions) have been also evaluated. The frequency response function (sometimes called as transfer function) plays significant role in the extracting of the modal parameters of the tested body. The corresponding procedure is strongly dependent on the model of the mechanical behaviour of the tested potato tuber. It has been found that the mean values of these functions are typical for the different cultivars of the potatoes.

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