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BEHAVIOUR OF SELECTED TABLE FATS AT THE DYNAMIC LOADING

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Abstract

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The new method of the evaluation of the mechanical behaviour of fats has been designed. This method is based on the evaluation of the fat response to dynamic loading. Dynamic loading has been realized by fall of bar impact. Response function has been represented by the time history of the fat surface displacement. Response of the tested table fats have been evaluated both in the time and frequency domain. Two factors affected rheology of the examined fat products: temperature of the measurement and product origin. The influence of fat content can be described namely in the frequency domain. The results obtained between 14 and 20 °C showed significant differences in the fat rigidity.

table fat, rheology, dynamic loading, surface displacement, spectral function

The hardness of a fat or fat-structured product is an important property that strongly influences the perceived texture of a food product. Many studies evaluating hardness of fats have focused on butter, milk fat, shortenings, and spreads using both the small- and large-deformation mechanical testing (Dolby, 1941a, b; Haighton, 1959; Dixon, 1974; DeMan, 1976; Rohm and Ulberth, 1989; Rohm, 1993; Rohm and Weidinger, 1993; Rousseau et al., 1996; Herrera and Hartel, 2000; Wright et al., 2001).

Mechanical testing of fats can be performed using large- or small-deformation techniques. Large-deformation methods such as cone penetrometry and parallel plate compression lead to irreversible structural breakdown of the network, and parameters such as yield force F_y and compression modulus (K) can be determined (Rohm, 1993). On the other hand, small-deformation methods, such as small-amplitude dynamic shear rheology, do not lead to irreversible structural breakdown of the network (Wright et al., 2001). Parameters such as the storage modulus (G`), loss modulus (G``), as well as tanδ=G``/G` can be determined. These parameters are usually determined from the linear viscoelastic region (LVR) of the material. Both types of rheological measurements can provide substantial information on the structure of the fat crystal network (Marangoni and Rousseau, 1998). Another kind of the testing uses the indentation technique. This procedure enables to obtain main parameters of the rheological models (Nedomová et al., 2008).

The present paper deals with a non-destructive experimental technique. This method consists in the use of dynamic excitation and response analysis. Dynamic excitation and response analysis is an acceptable method for determination of physical properties for quality evaluation of fresh products. Their response to impact and sonic excitation has been well documented in the literature for the last three decades. Many researchers have analysed acoustic impulse responses in various kinds of products (Hayashi et al., 1995). This paper is focused on the study of the response of some table fats to the non-destructive impact loading.

MATERIALS AND METHODS

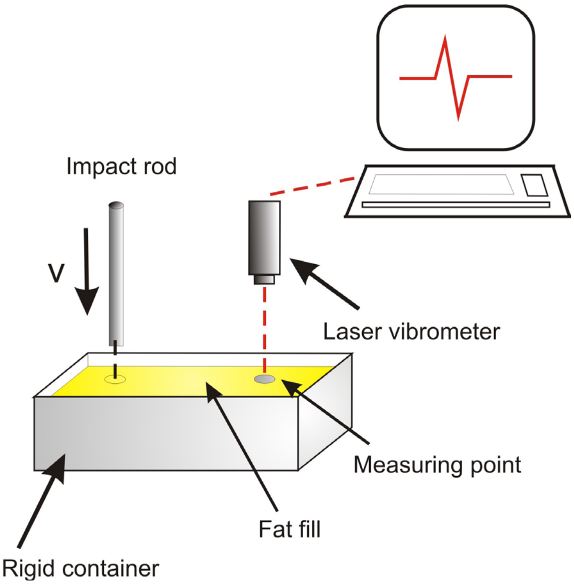
Following table fats have been used for the experiments – see Table I.

The impact tests were carried out using an impact device specially designed and built for fat measurements – see Fig. 1.

The impact set-up consisted of a free-falling cylindrical bar (6 mm in diameter, 200 mm in height – made from aluminium alloy). The bar was instrumented by strain gauges. This instrumentation

I: *The used fats*

Fat	Type of fat	Fat content (%)	Water content (%)
A	Table BUTTER (Poland, producer 1)	84.25	14.12
B	Table BUTTER (Belgium)	82.75	15.75
C	FRESH BUTTER (Czech Republic)	84.53	14.74
D	Table BUTTER (Poland, producer 2)	83.75	15.24
E	Three-quarter-fat butter	62.29	34.53
F	FRESH BUTTER (Czech Republic)	79.00	17.67
G	Fat with 15 % milk fat, 85 % vegetable fat	74.77	23.24
H	Vegetable fat	82.25	22.61
I	Vegetable fat with olive oil	80.75	23.44



1: *Experimental set up*

enables to record the time history of the force at the interface between fat and bar. The surface displacement as well as the surface velocity at the distance of 30 mm from the point of the bar impact are measured using the laser-vibrometer.

The fat response was picked up through an amplifier and a commercial A/D PC board to the PC, which simultaneously served as the data acquisition system. An optical sensor was used to trigger the acquisition. The signal was sampled at a rate of 200,000 samples/s for a period of 15 ms. Instead of time dependent response functions; the MATLAB computer program transformed the response from time to frequency domain by means of Fast Fourier Transform (FFT). The impact velocity of the bar has been kept constant (2.1 m/s).

Experiments have been performed at temperatures well below the glass transition temperature. The fat F has been tested at the different temperatures.

RESULTS AND DISCUSSION

In the Fig. 2 examples of the experimental records of the force versus time are displayed.

One can see a good reproducibility of the experiments. The qualitative features of these functions are the same for nearly all tested fats. Fat H and I represent the exception – see Fig. 3.

The all functions force – time, F(t), can be characterized by the three main parameters:

- Maximum of the force F_m
- Rise time of the force – time pulse, t_I
- The time of the force pulse duration, λ

The values of these parameters are given in the Tab. II.

The values of the maximum force are very different for tested fats. The distribution of these forces is shown in the Fig. 4.

The force versus time curves is sensitive to the temperature. This effect is shown in the Fig. 5.

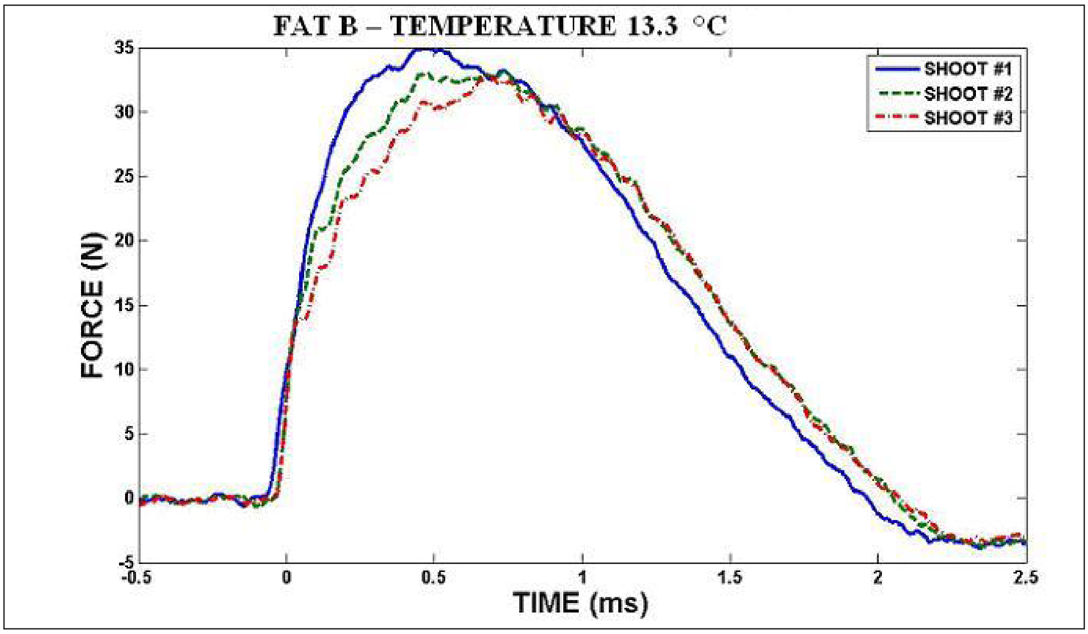
One can see that increase of temperature leads to a change from the shape of F(t) curve shown in the Fig. 2 to the shape displayed in the Fig. 3. The influence of the temperature on the maximum value of the force is shown in the Fig. 6.

Response of the fat to the impact loading is described by the surface displacement versus time curves. Examples of these curves are given in the Fig. 7.

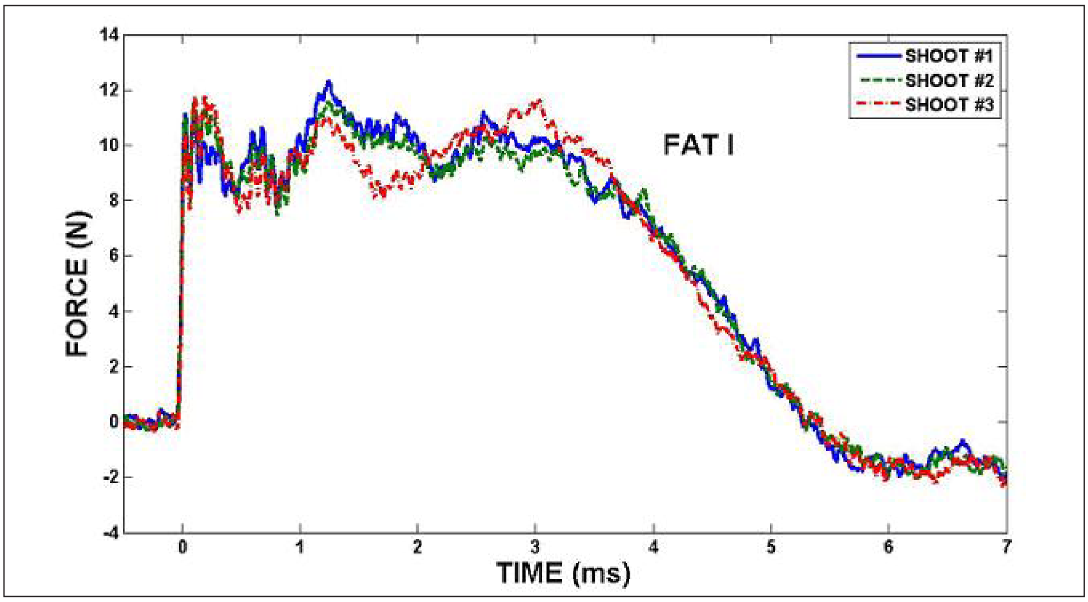
The leading part of this curve corresponds to the propagation of the surface wave. The qualitative features of these curves are the same for all tested fats. The influence of the temperature on these curves is shown in the Fig. 8.

The increase of temperature affects the initial part of the displacement – time curve.

The response analysis in the time domain can be also substituted by the analysis in the frequency domain. This procedure is based on the Fourier transform (see e.g. Stein et Shakarchi, 2003). The function f(t) in the time domain is substituted by the spectral function F(ω).The transform into the frequency domain will be a complex valued function, that is, with magnitude and phase. The magnitude of the spectral function of the force is shown in the Fig. 9.



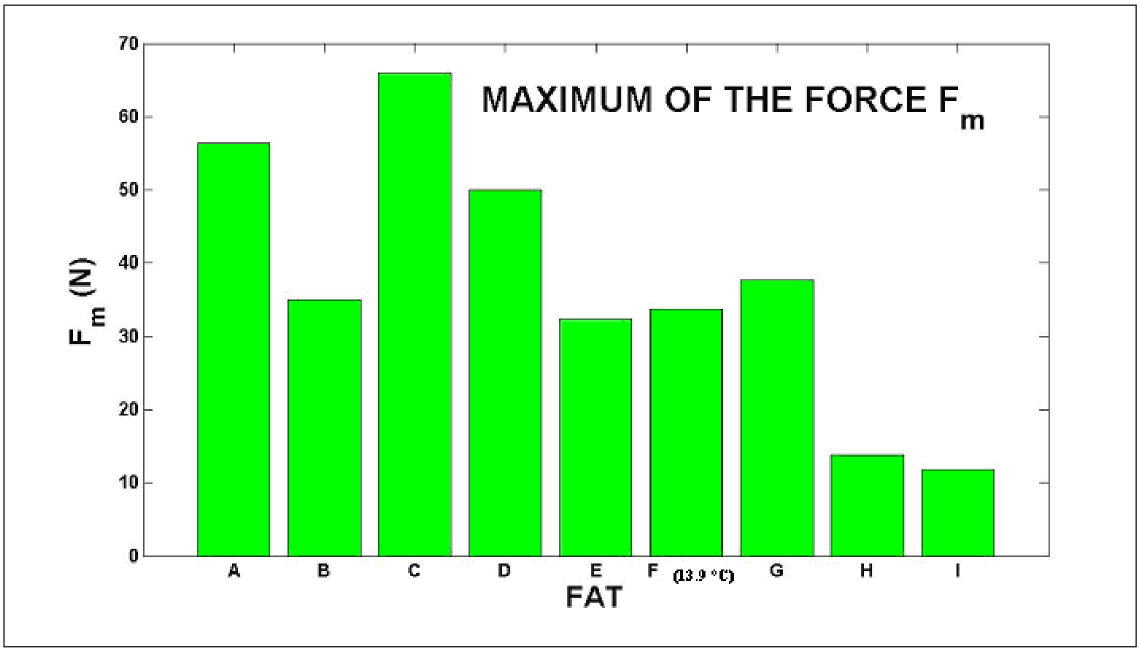
2: *Experimental records of the force at the contact between fat and the striking bar*



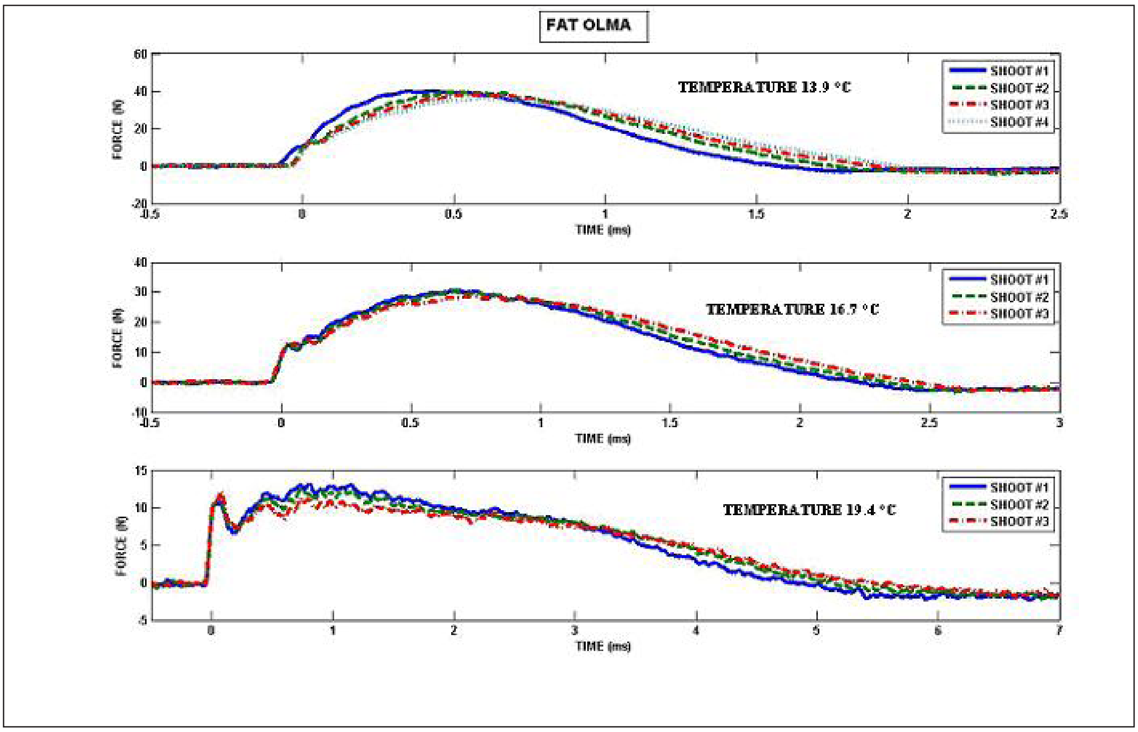
3: *Examples of the experimental records force – time. Another type of the time history*

II: *Parameters of the force – time functions*

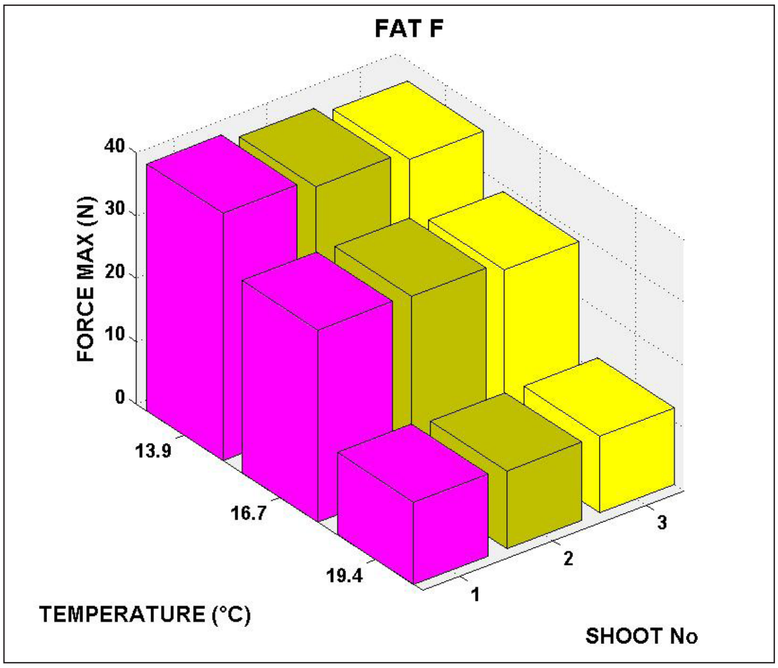
Fat	Temperature (°C)	F_m (N)	t_I (ms)	λ (ms)	T (1)
A	14.4	56.3	0.412	1.418	0.076
B	14.6	34.9	0.468	2.07	0.08642
C	13.3	66.0	1.122	3.52	0.06212
D	19.4	50.0	0.592	1.344	0.1324
E	15.5	32.2	0.308	2.148	0.4256
F	13.9	39.7	0.348	1.6	0.09756
G	16.4	37.7	0.4	1.156	0.177
H	13.9	13.8	0.34	5.34	0.08807
I	14.2	11.8	0.196	5.4	0.09554



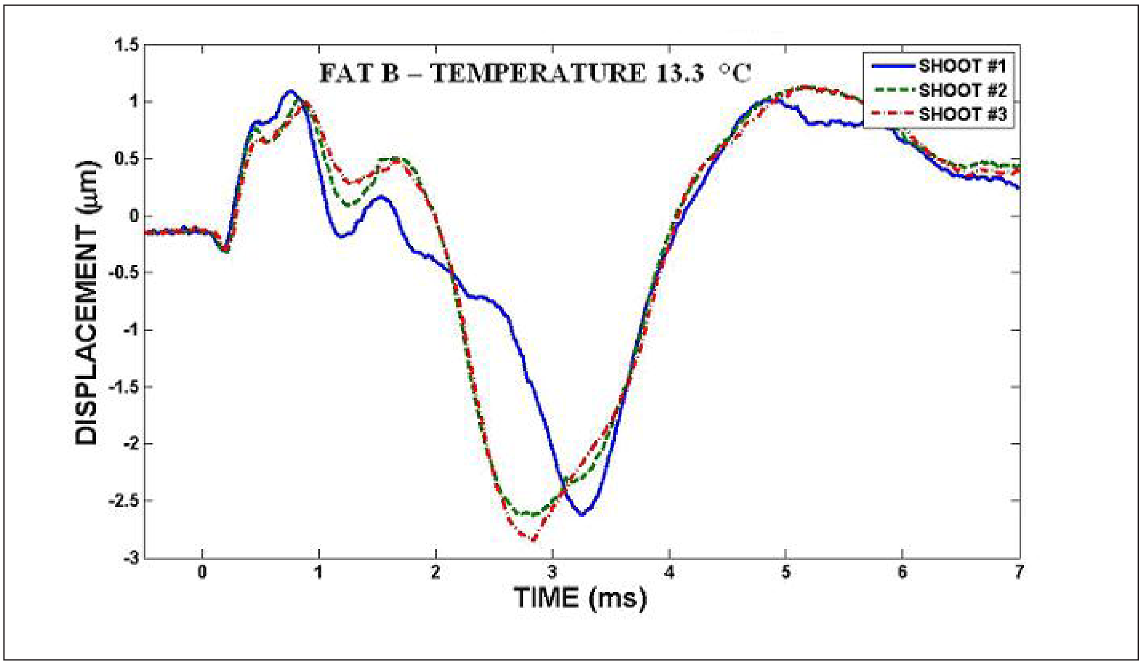
4: *Maximum of the force for different fats*



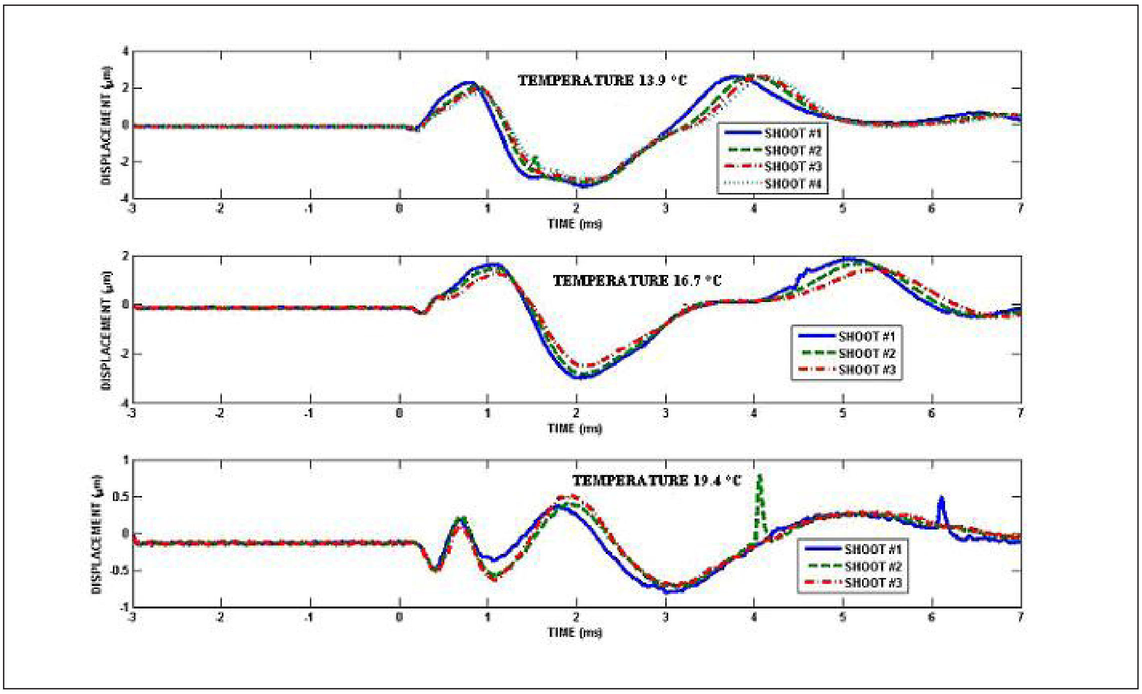
5: *The effect of the temperature on the force at the contact between fat and striking bar*



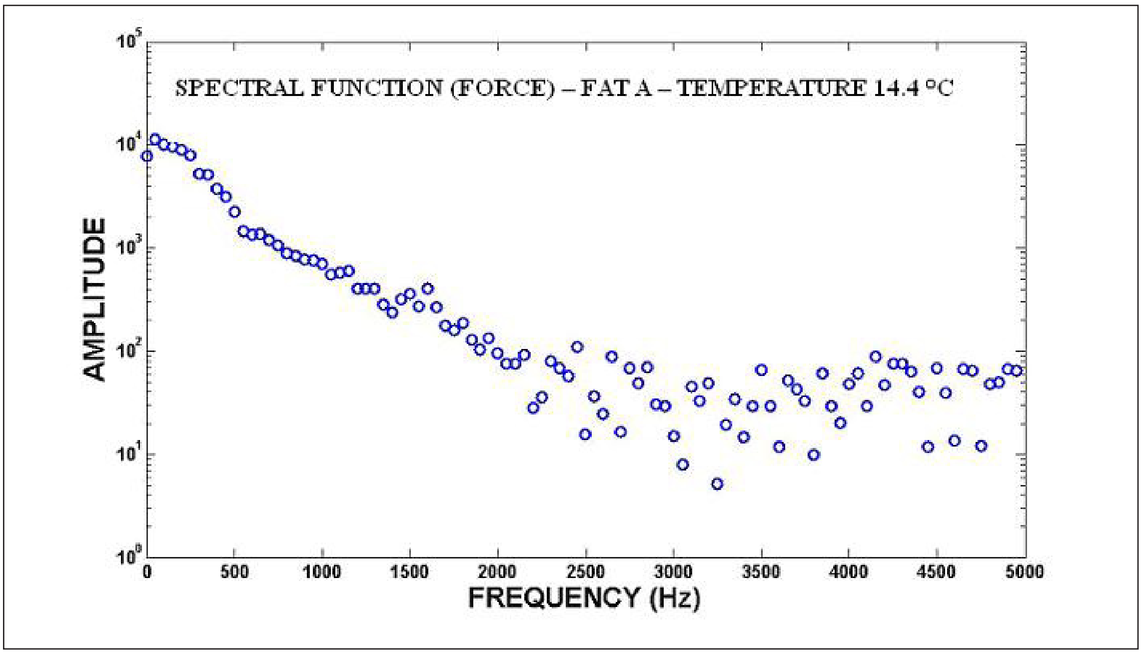
6: *Maximum of the force at the different temperatures*



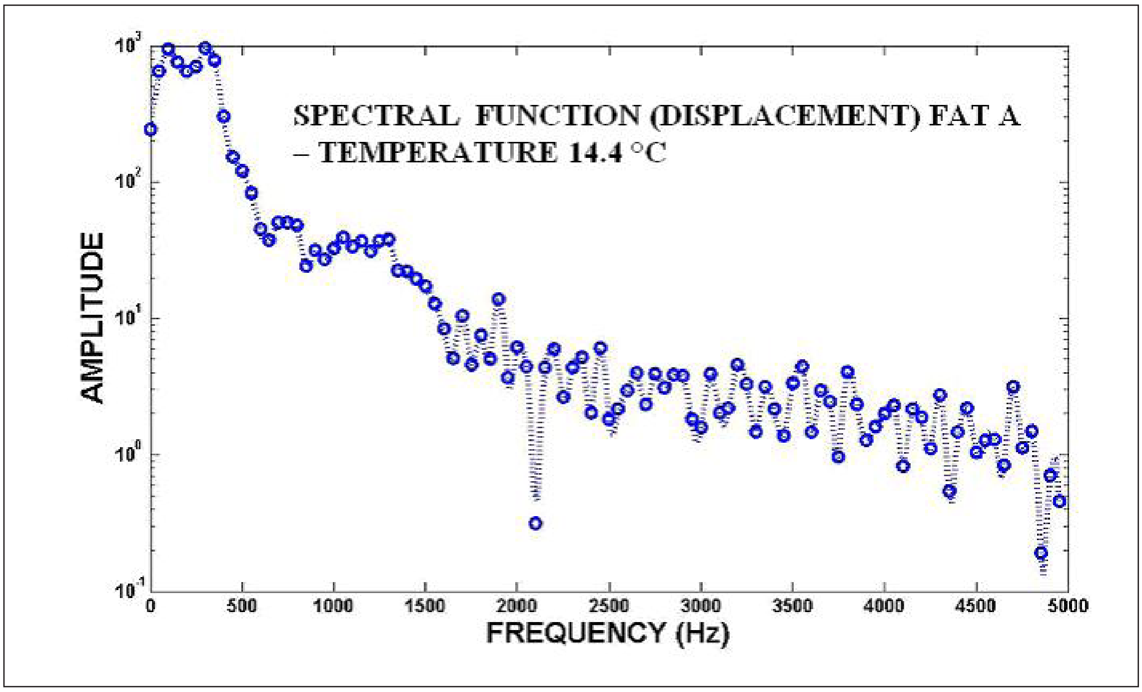
7: *Examples of the displacements of the fat surface*



8: *The effect of the temperature on the displacement of the fat surface*



9: *Example of the frequency dependent amplitude of the spectral function*



10: *Amplitude spectral function – displacement*

Example of the magnitude of the spectral function of the displacement is shown in Fig. 10. This function is characterized by a maximum. The corresponding frequency to the peak amplitude (Fig. 11) is a good estimate of the natural frequency. It is usually called as the dominant frequency. The half power method generates an estimate of the damping ratio, ξ. The damping ratio, ξ can be found using he following equation

$$\xi = \frac{w_2 - w_1}{2w}.$$

The dominant frequency as well as the damping ratio increases with the increase of the fat content – see Figs. 12, 13.

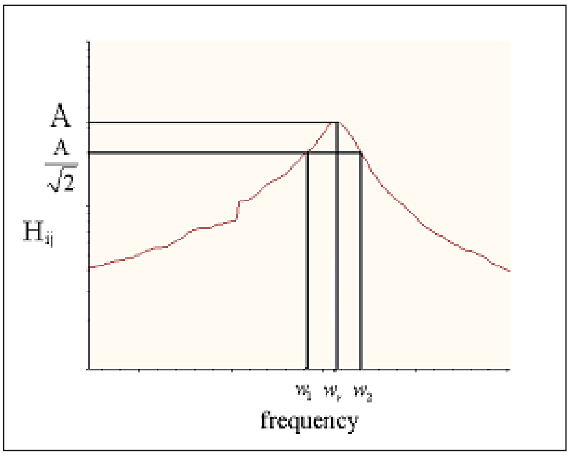
The knowledge of the spectral function of the force, F(ω), and the surface displacement X(ω) enables to define the transfer function (frequency response function] as:

$$T(w) = \frac{S(w)}{F(w)}.$$

Example of the amplitude of this function is displayed in the Fig. 14.

There are several local maxims. The mean value of the amplitude lies below one. The mean values are given in the Table I. This function is also dependent on the temperature. The Influence of the temperature is shown in the Fig. 15.

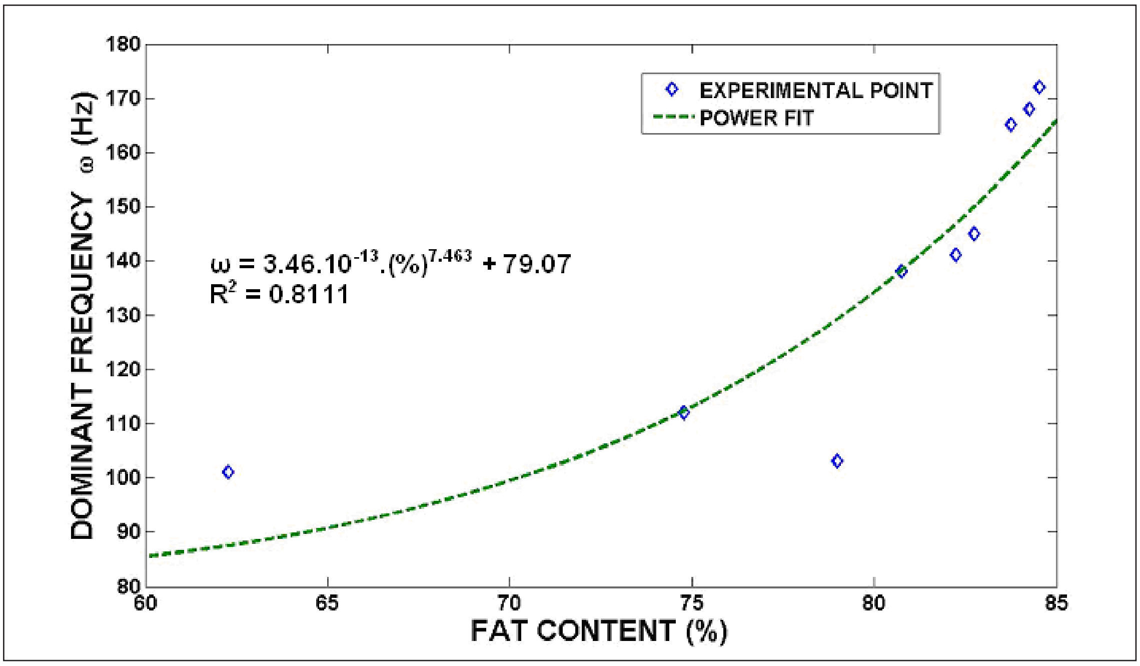
The mean values of the transfer function amplitude are different for the different fats. This value can be thus used for the fat identification.



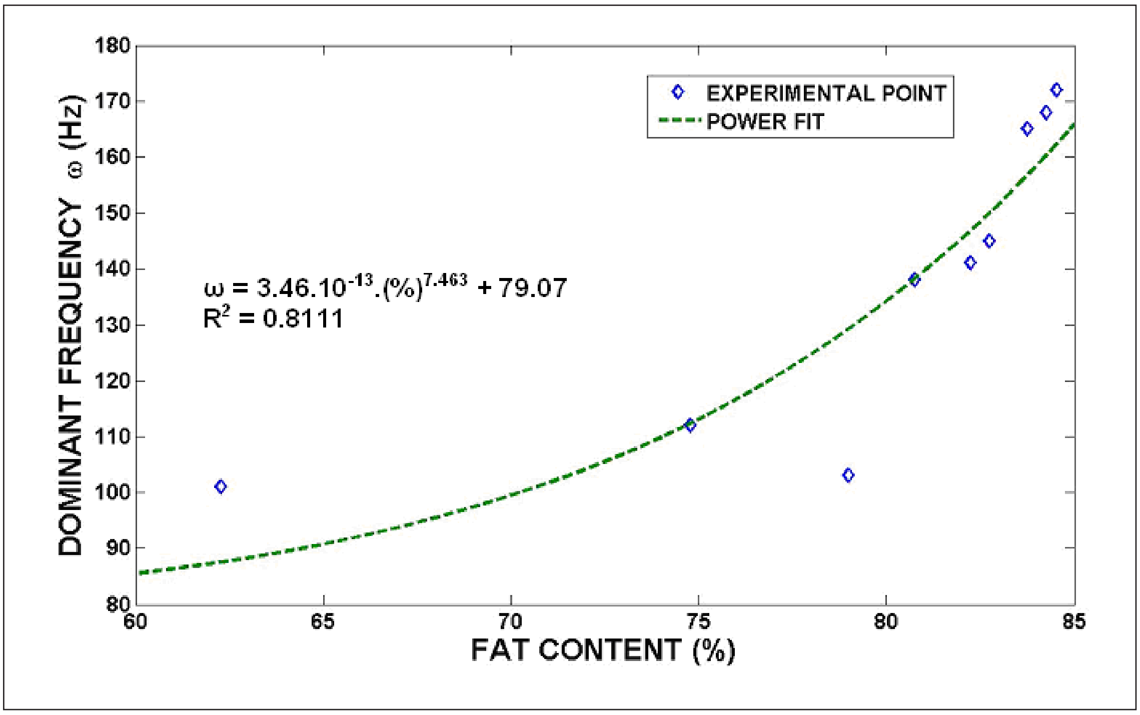
11: *Peak picking on the amplitude of a frequency response function using the half power method*

CONCLUSSIONS

In the given paper the main characteristics describing the response of selected table fats to the dynamic loading have been found. These parameters have been evaluated not only in the time domain, but also in the frequency domain, using the Fourier transform. The suggested parameters are very convenient for the description of the mechanical behaviour of different fats. It has been found that the mechanical behaviour of the tested fats was very sensitive to

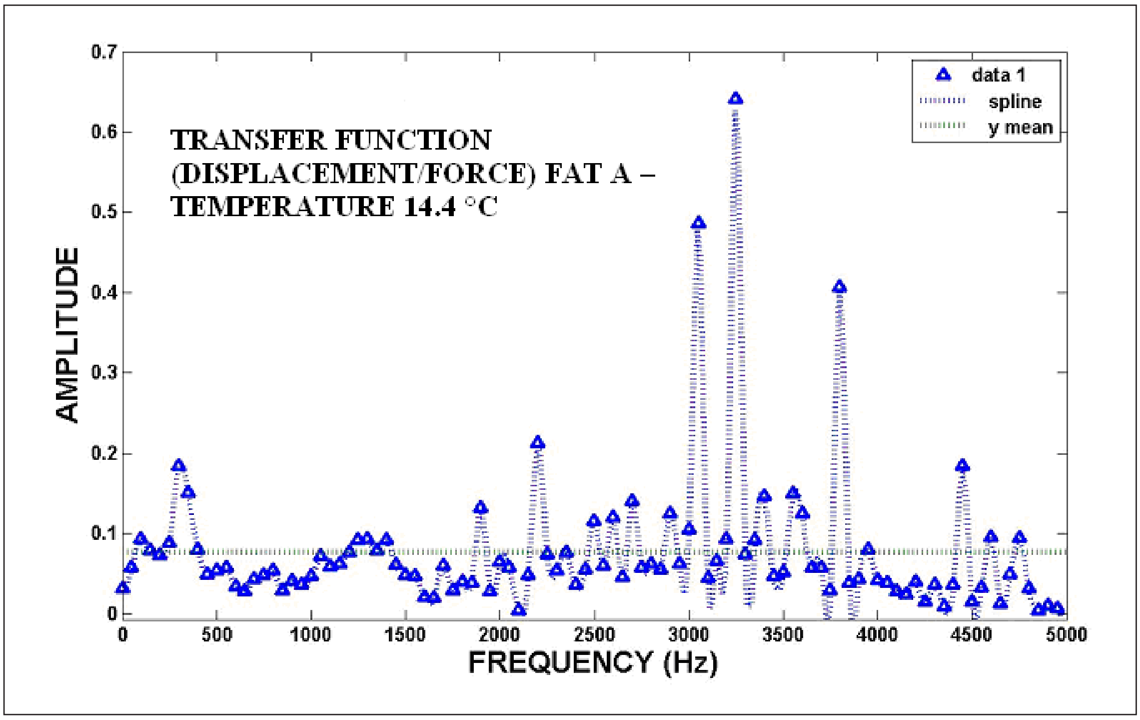


12: *The influence of the fat content on the dominant frequency*

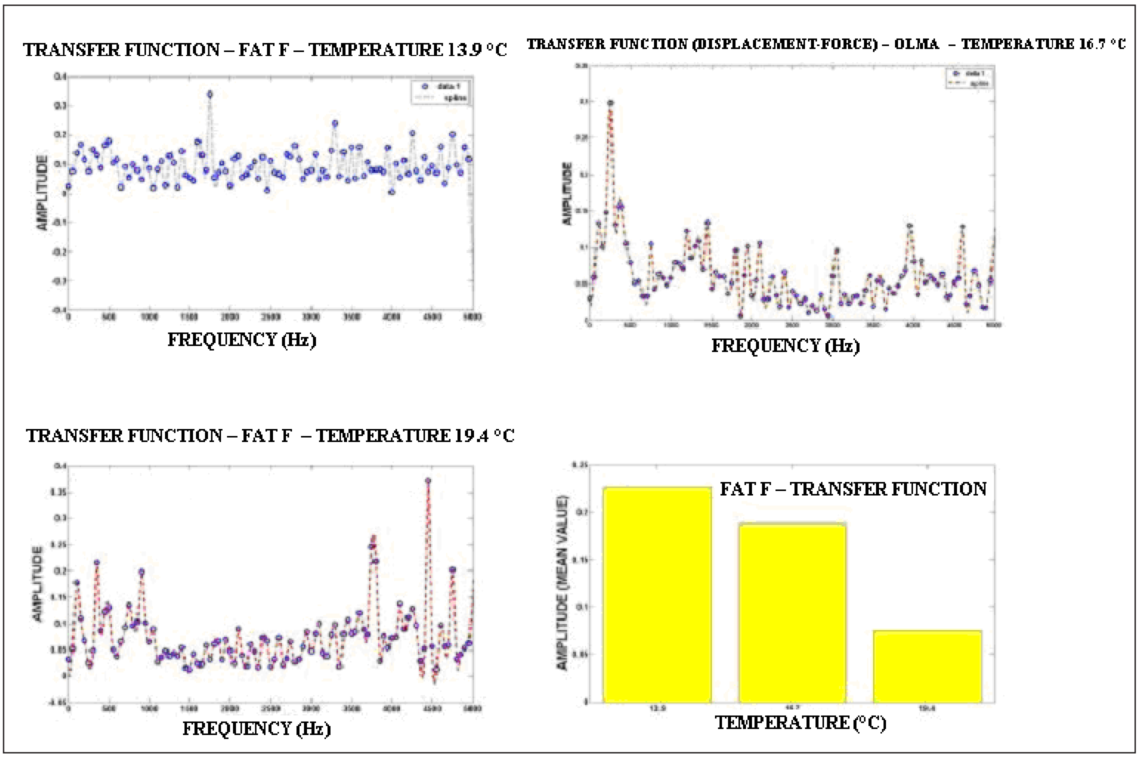


13: *The influence of the fat content on the damping ratio*

the temperature changes. This behaviour is also significantly affected by the origin of the fat products. At the same time the influence of the fat content on the most of the response functions parameters has not been detected. The exceptions are the dominant frequency and the damping ratio. These parameters describe the fat response in the frequency domain. It means the frequency analysis of the fat response should be studied in more details. Generally the proposed method seems to be very promising for the study of the fat rheology. Namely the possibility of the verification of the validity of the constitutive equations represents the main advantage of this method.



14: *Amplitude of the transfer function*



15: *Temperature dependence of the transfer functions*

SUMMARY

A new experimental method based on the dynamic excitation and response analysis has been used to description of the mechanical behaviour of selected table fats. The loading of the tubers has been performed by the impact of the free falling rod. The force at the bar – fat contact has been recorded using the laser vibrometer. 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 temperature. The parameters are also different for the different table fats. The response of the tuber has been described by the time history of the fat 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 temperature. 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 has been different for different table fats. The significant influence of the temperature has been also reported. There is a chance to use this frequency also for the description of the mechanical behaviour of the table fats. 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 table fats. Dominant frequency as well as the damping ratio increased with the increase of the fat content.

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SOUHRN

Chování vybraných stolních tuků při dynamickém zatěžování

V dané práci bylo zkoumáno reologické chování několika druhů másel a směsných tuků. Pro toto studium byla použita nová metoda založená na stanovení odezvy zkoumaného tuku na dynamické zatížení představovaném dopadem tyče kruhového průřezu. Tento postup umožňuje stanovit časový průběh síly v místě kontaktu tyč – tuk. Průběh závislostí síla – čas je v zásadě popsán třemi parametry, a to maximální hodnotou síly, dobou dosažení tohoto maxima a dobou trvání zatížení. Tyto parametry závisejí jak na druhu tuku, tak na teplotě. Odezva materiálu byla popsána časovou závislostí výchylky volného povrchu tuku. Výchylka byla stanovena pomocí laserového vibrometru. Tato výchylka má zhruba sinusovitý charakter a odpovídá šíření povrchové vlny napětí. Byly stanoveny základní parametry této odezvy, a to jak v časové, tak ve frekvenční oblasti. Ukazuje se, že v časové oblasti jsou parametry popisující odezvu, např. maximum výchylky apod., závislé na druhu tuku a rovněž na teplotě. Byly stanoveny odezvové funkce ve frekvenční oblasti, a to pomocí Fourierovy transformace. Získané funkce umožňují stanovit zejména přenosovou funkci, která popisuje vibrační vlastnosti zkoumaného materiálu. Z daných funkcí je pak možné stanovit i útlum jednotlivých frekvenčních složek. Ukázalo se, že navržené parametry jednoznačně charakterizují mechanické chování tuků a mohou tak sloužit k jejich indentifikaci. Z výsledků vyplynulo, že toto chování je v prvé řadě určeno teplotou a původem tuku. Na druhé straně se neukázal výraznější vliv změn ve složení. Jedinou výjimkou jsou dominantní frekvence a útlum, tzn. parametry popisující odezvu tuků ve frekvenční oblasti. Obě tyto veličiny jsou jednoznačně rostoucí funkcí obsahu tuku. Navržená metoda je velice vhodná i pro verifikace modelů reologického chování tuků, které byly stanoveny pomocí jiných, vesměs destruktivních metod.

stolní tuk, reologie, dynamické zatěžování, výchylka povrchu, spektrální funkce

REFERENCES

DEMAN, J. M., 1976: Texture of fats and fat products. In: *Rheology and Texture in Food Quality,* (ed.) DEMAN, J. M. Westport: AVI Publishing Company, 355–381. ISBN 0870551973.

DIXON, B. D., 1974: Spreadability of butter: Determination. 1. Description and comparison of five methods of testing. *Australian Journal of Dairy Technology*, 29, 15–22. ISSN 1364-727X.

DOLBY, R. M., 1941b: The Rheology of Butter. II. The Relation Between the Rate of Shear and Shearing Stress. The Effect of Temperature and of Reworking on Hardness and/or Structural Viscosity. *Journal of Dairy Research*, 12, 337–343. ISSN 0022-0299

DOLBY, R. M., 1941a: The rheology of butter. I. Methods of measuring the hardness of butter. *J. Dairy Research,* 12, 329–336. ISSN 0022-0299.

HAIGHTON, A. J., 1959: The measurement of the hardness of margarine and fats with cone penetrometers. *Journal of the American Oil Chemists' Society*, 36, 8: 345–348. ISSN 0003-021X.

HAYASHI, S., SUGIYAMA, J., OTOBE, K., 1995: Non-destructive quality evaluation of fruits and vegetables by acoustic transmission waves. In: *Proceedings of International Symposium on Automation and Robotics in Bioproduction and Processing*. Kobe University, 227–234.

HERRERA, M. L. and HARTEL, R. W., 2000: Effect of processing conditions on crystallization kinetics of a milk fat model system. *Journal of the American Oil Chemists' Society,* 77, 11: 1177–1187. ISSN 0003-021X.

MARANGONI, A. G. and ROUSSEAU, D., 1998: The influence of chemical interesterification on the physicochemical properties of complex fat systems. 3. Rheology and fractality of the crystal network. *Journal of the American Oil Chemists' Society,* 75, 11: 1633–1636. ISSN 0003-021X.

NEDOMOVÁ, Š., SEVERA, L., 2008: Constitutive equation of butter at static loading. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* 56, 5: 147–152. ISSN 1211-8516.

ROHM, H., 1993: Rheological behaviour of butter at large deformations. *Journal of Texture Studies*, 20, 4: 409–418. ISSN 0022-4901.

ROHM, H. and ULBERTH, F., 1989: Use of magnitude estimation in sensory texture analysis of butter. *Journal of Texture Studies*, 20, 4: 409–418. ISSN 0022-4901.

ROHM, H., AND WEIDINGER, K. H., 1989: Rheological behaviour of butter at small deformations. *Journal of Texture Studies*, 24, 2: 157–172. ISSN 0022-4901.

ROUSSEAU, D., HILL, A. R., MARANGONI, A. G., 1996: Restructuring butterfat through blending and chemical interesterification. 3. Rheology. *Journal of the American Oil Chemists' Society,* 73, 8: 983–989. ISSN 0003-021X.

STEIN, E. M., SHAKARCHI, R., 2003: *Fourier Analysis: An Introduction*. Princeton University Press, 311 p. ISBN 0-691-11384-X.

WRIGHT, A. J., SCANLON, M. G., HARTEL, R. W., MARANGONI, A. G., 2001: Rheological properties of milkfat and butter. *Journal of Food Science,* 66, 8: 1056–1071. ISSN 0022-1147.

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