Journal of Food Engineering 112 (2012) 346–351

Contents lists available at SciVerse ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Studies on determination of mathematical relationships between rapeseed oil content and electrical properties of butter and fat mixes

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ARTICLE INFO

Article history:
Received 21 December 2011
Received in revised form 12 March 2012
Accepted 19 April 2012
Available online 3 May 2012

Keywords:
Electrical parameters
Butter
Fat mixes
Rapeseed oil

ABSTRACT

This manuscript presents results of a study that was aimed at determining mathematical correlations between the content of rapeseed oil in fat mixes and their electrical parameters, conductance and capacitance ones.

The conducted correlation and linear regression analyses of rapeseed oil content (C_{RO}) in the function of changes in electrical parameters of fat mixes demonstrated that in a frequency range of 20 Hz to 2 MHz, mathematical correlations were achieved that could be described with the equation: $y = ax \pm b$ at $0.943 \leqslant r \leqslant 0.989$ and $\alpha = 0.000$, between values of conductance parameters – impedance (Z) and admittance (Y), capacitance parameters – parallel equivalent capacitance (C_p) and quality factor (Q_p), and rapeseed oil content of the fat mixes examined. The highest correlations were reported between rapeseed oil content of the mixes and Q_p values, which indicates that the content of rapeseed oil (C_{RO}) in fat mixes may be determined the most accurately based on Q_p measurements and calculations using a mathematical equation $C_{RO} = -407.562 \pm 33.861 \times Q_p + 53.990 \pm 3.054$, at $r = -0.990$ and $\alpha \leqslant 0.001$. It was stated that the correlations achieved in a measuring frequency range from 20 Hz to 2 MHz formed grounds for further investigations aimed at elaborating a method for rapid evaluation of the content of rapeseed oil and other vegetable oils in fat mixes, and for detecting their adulterations based on measurements of electrical parameters of conductance and capacitance.

1. Introduction

Butter is one of the most important products of the dairy sector in Europe and many other countries world wide (Staniewski, 2009). Pursuant to regulations of the European Union (Council Regulation 2991/94), butter constitutes a food product with milk fat content not lesser than 80% and not more than 90%, with the maximum water content of 16%, and with fat-free substance of milk reaching 2% (Kolanowski and Świderski, 2003). A charge of nutritionally unfavorable traits characterizing butter, including a high content of saturated fatty acids and a relatively low content of unsaturated fatty acids, was one of the reasons of launching a health-promoting trend of the 1990's aimed at changing consumption preferences from butter into margarine. Owing to a high content of cholesterol, claimed likewise saturated fatty acids to be an atherogenic factor, butter has begun to be perceived as a food product yielding negative effects on body. In this promotion of a healthy lifestyle, a response of producers to the high-calorific and atherogenic butter were margarines that were additionally meeting consumers' expectations in terms of spreadability (Cichosz, 2007; Łuszczak, 2009).

The market of table spreads, however, includes not only butter and margarines but also produced by the dairy industry and increasingly often by the fat industry the so-called fat mixes, i.e. products based on milk fat with the addition of oils, particularly the rapeseed, palm and sunflower ones (Juśkiewicz et al., 1993; Szajner, 2007), that are supposed to be an equivalent of both butter and margarine. The market of table spreads is additionally completed by fat products with a reduced calorific value. Almost fourfold higher prices of butter compared to those of the products offered by the fat industry (e.g. margarine) make it a relatively expensive table spreads to consumers (Świetlik, 2008). This situation has encouraged some dishonest producers to introduce cheaper, extrinsic fats (mainly of plant origin) to butter. A lack of respective information on products' labels available to consumers violates legal regulations binding in this respect and economic interests of a consumer. This additionally violates economic interests of reliable producers of dairy products. For it simply means product's adulteration. An additional motive for the adulteration of butter by its producers results from the fact that the addition of a small portion of the vegetable oil is undetectable in connection with the effects of seasonal variability and environmental factors on

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0260-8774/$ - see front matter
http://dx.doi.org/10.1016/j.jfoodeng.2012.04.010

the chemical constitution of butter (Tynek and Pawłowicz, 2006; Nogala-Kałucka et al., 2008).

In the situation of a need for constant monitoring of this phenomenon, and thus of a need for rapid acquisition of information in this respect, analytical methods are searched for that would enable fast evaluation of the chemical composition of table spreads, including mainly fat mixes, and verification whether they meet criteria stipulated for this type of food products. Contemporarily, the most commonly applied methods that allow high-precision detection of a non-labeled addition of extrinsic fat include chromatographic methods. They may be used to determine the whole spectrum of fatty acids and contribution of individual acids in the finished product (Nogala-Kałucka et al., 2008; Ulberth, 2003; Stołyhwo and Rutkowska, 2007). A reference method is the triacylglycerols assay (Destaillats et al., 2006; Stołyhwo and Rutkowska, 2007). To this end, there may also be used methods that consist in the determination of tocopherols (Stołyhwo and Rutkowska, 2007; Nogala-Kałucka et al., 2008) and phytosterols (Kamm et al., 2002; Bocheńska et al., 2007) with a technique of liquid chromatography (HPLC). Out of the physical methods, the presence of extrinsic fats in butter may also be detected with the differential scanning calorimetry (DSC) method (Chmielowski and Rak, 1996; Kocjan, 2000).

The major drawback of methods for adulteration detection is a complicated analytical procedure, which results in the necessity of their performance by specialist laboratories as well as in very high time consumption of the analysis (Tynek and Pawłowicz, 2006; Nogala-Kałucka et al., 2008). In times of highly advanced automation, it seems highly significant therefore to develop rapid instrumental methods for the detection of butter adulteration with vegetable oils.

In recent years, investigations of milk and dairy products have been focused on their electrical properties. The measurements of electrical conductance of milk is applied to investigate transformations of raw milk constituents during the homogenization process and to the assessment of its qualitative changes during the storage process (Żywica and Budny, 2000; Banach et al., 2008). The electrical properties have also been used to demonstrate differences between natural and synthetic milk (Sadat et al., 2006). They have also been reported to be applicable in determining the level of ionic calcium in raw milk and in detecting milk adulteration by its dilution with water (Czerniewicz et al., 2002; Mabrook and Petty, 2003a). Techniques of measurement of dielectrical properties are applied in the analysis of the chemical composition and ripeness of cheese, based on which models have been developed for predicting contents of water and salt in the process of its production (Everard et al., 2006).

In view of a wide applicability of electrical properties in dairy production, an outstandingly important direction is to determine the feasibility of their application in analyses of butter and evaluation of its quality. By using microwaves, it is possible to determine dielectrical properties of salted and non-salted butter (Ahmed et al., 2007). A dielectric constant may also be a basis of a simple method for the determination of water content of butter. Reference works report also on attempts undertaken to compare the electrical properties of butter and other fats, including vegetable oils or lard (Parkash and Armstrong, 1969; Hu et al., 2008; Lizhi et al., 2008; Møller et al., 2010). The available literature lacks, however, reports on the feasibility of using electrical properties for the determination of the content of vegetable oil in fat mixes.

Hence, taking the above into account and based on our unpublished data, a study was undertaken the objective of which was to determine the effect of rapeseed oil addition to butter and the frequency of measuring voltage on the electrical properties of fat mixes, and then to determine mathematical correlations between the content of rapeseed oil in fat mixes and their electrical parameters (conductance and capacitance ones), and to describe those correlations with mathematical equations.

2. Material and methods

The experimental material were fat mixes ($n = 4$) produced in the mixing process of butter and rapeseed oil in the following ratios: 90/10, 80/20, 70/30, and 60/40. The butter produced by the MLEKOVITA Dairy Cooperative were used both for preparing fat mixes and as a comparative material. The basic chemical specification of butter was as follows: fat content – 82.89%; fat-free dry matter – 1.32%; water content – 15.79%. The chemical composition of the rapeseed oil used in the study was as follows: long-chain saturated fatty acids 10.13%, monounsaturated fatty acids 47.10%, polyunsaturated fatty acids 40.98%, water content 0%, as compared with the fatty acids composition of butter used in the study: short-chain fatty acids 12.57%, long-chain saturated fatty acids 66.49%, monounsaturated fatty acids 18.24% and polyunsaturated fatty acids 3.39%.

The butter and the fat mixes with oil content of 10%, 20%, 30% and 40% were heated to a liquid state and then their 350 ml portions were poured into glass containers with two plate electrodes mounted inside. The electrodes were made of acid-proof steel and were tightly mounted to opposite walls of the container (those with a greater area). Afterwards, the samples were transferred to a climatic chamber Memmert, type ICP 500, Schwabach FRG, Germany and heated to a temperature of 40 °C. After this temperature has been reached, the containers filled with samples were transferred to a metal container equipped with a water jacket which were connected to an ultrathermostat. Next, the following measurements were conducted: electrical conductance parameters (impedance – Z; admittance – Y), and for electrical capacitance parameters (parallel equivalent capacitance – C_p, quality factor – Q_p, series equivalent capacitance – C_s, quality factor – Q_s), with the use of an LCR type E4980a measuring device (by Agilent Technologies) in a frequency range from 20 Hz to 2 MHz and at the voltage of 200 mV. The measurement of each electrical parameter was conducted in three replications for each sample. The scheme of a measurement system for the examination of the electrical properties of butter and fat mixes was presented in Fig. 1.

The analysis of the electrical properties of fat mixes and butter was conducted according to an RCC model (Fig. 2) elaborated by our research group based on our previous studies with: milk, fruit juices and fruit purée, and meat (Pierzynowska-Korniak et al., 2003; Żywica et al., 2005; Banach and Żywica, 2010; Żywica et al., 2012), but also based on results of investigations published in available research works (Mabrook and Petty, 2003a,b).

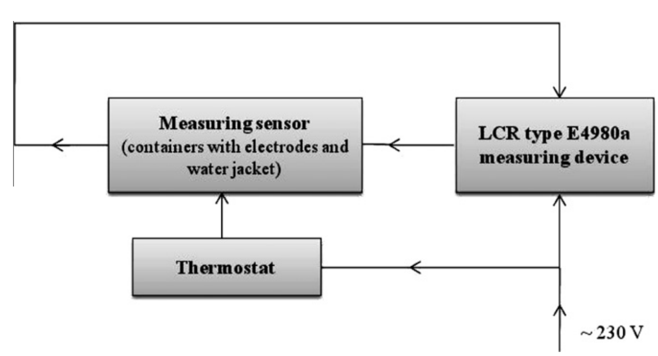

Fig. 1. Scheme of measurement system for electrical properties examination of butter and fat mixes.

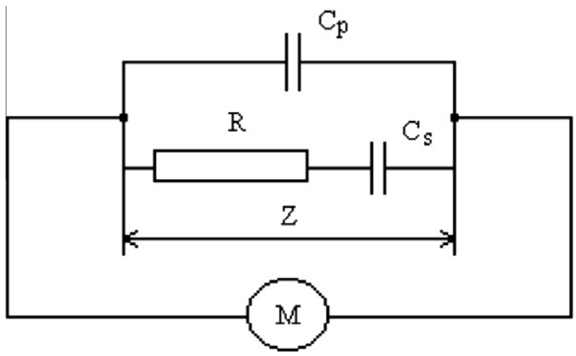

Fig. 2. Scheme of a measuring system of electrical properties of raw materials and food products: Z – impedance, R – resistance, C_s – series equivalent capacitance, C_p – parallel equivalent capacitance, M – measuring device (Pierzynowska-Korniak et al., 2003; Żywica et al., 2005).

In order to determine correlations between the electrical properties of fat mixes and butter, and rapeseed oil content in those products, a correlations and linear regression were computed with the use of Excel and Statistica 6.0 software. The error of regression parameters (a,b) was computed using MS Excel 2007 by means of Solver Aid macro developed by De Levie (2008).

3. Results and discussion

3.1. Conductance parameters – impedance (Z)

Measurement results presented in this manuscript demonstrated that the increase in oil content of fat mixes from 0% to 40% caused an increase in impedance values. For the frequencies of measuring voltage, selected based on the preliminary study and presented in Table 1, this increase ranged from 84% to 108%, with the greatest changes (108%) reported at the frequency of 1 MHz and the smallest ones (84%) at the frequency of 500 Hz.

The statistical analysis of results of the impedance measurements of the fat mixes examined showed significant ($\alpha \leqslant 0.01$) differences between its values obtained at particular frequencies of measuring voltage, at a specified oil content. The differences were not significant only between impedance values of the fat mixes with 40% oil content measured at the frequencies of 10 kHz and 1 MHz. Significant ($\alpha \leqslant 0.01$) differences were also reported between impedance values of the fat mixes with various (increasing from 0% to 40%) content of oil at specified frequencies of measuring voltage (Table 1).

3.2. Conductance parameters – admittance (Y)

Measurement results demonstrated that the increase in oil content of the fat mixes from 0% to 40% caused a decrease in admittance values, which for the frequencies of measuring voltage presented in Table 2 ranged from 47% to 52%. The greatest changes (52%) were observed at the frequencies of 100 kHz and 1 MHz, and the smallest ones (47%) at the frequency of 500 Hz.

The statistical analysis of admittance measurements of the mixes examined demonstrated significant ($\alpha \leqslant 0.01$; $\alpha \leqslant 0.05$) differences between its values obtained at particular frequencies of measuring voltage, at a specified oil content. Significant differences were not obtained between admittance values of butter and fat mix with 30% oil content at the frequencies of 100 kHz and 1 MHz, and – likewise for impedance measurements – between admittance values of fat mixes with 40% oil content measured at the frequencies of 10 kHz and 1 MHz. As in the case of impedance measurements, significant ($\alpha \leqslant 0.01$) differences were also obtained between admittance values of the fat mixes with various (increasing) contents of rapeseed oil, at specified frequencies of measuring voltage (Table 2).

As a result of measurements of conductance parameters (Z, Y) of fat mixes and butter, it was observed that the changes in impedance along with an increasing oil content were twice as high as these of admittance. Both in the case of admittance and impedance measurements statistically significant differences were obtained between values of these parameters along with an increasing oil content of the fat mixes examined. It indicates that further investigations into the determination of rapeseed oil content of fat mixes should be conducted by performing both impedance and admittance measurements (Tables 1 and 2).

The results of measurements of butter with rapeseed oil added confirm the results of our earlier study which showed that over the frequency range from 500 Hz to 2 MHz occured relationships between the oil content and the impedance and admittance of tested fat mixes. The highest changes of these parameters were observed over the frequency range 20–500 Hz. However, over this frequency range the above-mentioned relationships were not observed (our unpublished data).

3.3. Capacitance parameters – parallel equivalent capacitance (C_p), quality factor (Q_p)

The statistical analysis of results of measurements of parallel equivalent capacitance (C_p) and quality factor (Q_p) of the investigated fat mixes demonstrated significant ($\alpha \leqslant 0.01$) differences between its values obtained at particular frequencies of measuring voltage at a specified oil content. Significant ($\alpha \leqslant 0.01$) differences were also noted between C_p and Q_p values of the fat mixes with various (increasing from 0% to 40%) content of oil at specified frequencies of measuring voltage (Tables 3 and 4).

The presented in Tables 1–4 results of measurements of conductance and capacitance of butter and fat mixes showed that the values of capacitance parameters were to a significantly greater degree depended on the frequency of test voltage than the values of conductance parameters. Furthermore, the least changes in

Table 1
The results of impedance measurements (Z) of butter, fat mixes and rapeseed oil for selected frequencies of measuring voltage.

Selected frequencies	Impedance (Ω)					Z_{100} (MΩ)	Significance of differences (0–40%)
	Z_0	Z_{10}	Z_{20}	Z_{30}	Z_{40}		
500 Hz	92.513^a	94.568^a	134.451^a	162.894^a	176.781^a	119.988^a	**
1 kHz	89.264^b	92.641^b	132.555^b	158.987^b	175.180^b	59.120^b	**
10 kHz	84.370^c	89.579^c	129.522^c	153.244^c	172.959^c	5.776^c	**
100 kHz	83.208^d	88.565^d	128.560^d	151.580^d	172.313^d	0.546^d	**
1 MHz	82.927^e	88.685^e	129.314^e	151.707^e	172.953^{e,c}	0.050^e	**

Z_0 – impedance of butter; Z_{100} – impedance of rapeseed oil.
Z_{10-40} – impedance of fat mixes, the rapeseed oil content 10–40%.
[a,b,c,d,e] Significance of differences in columns, i.e. between impedance values obtained at particular (increasing) frequencies of the test voltage; upper small indexes – $\alpha \leqslant 0.01$.
** Significance of differences in rows, i.e. between impedance values in fat mixes of different (increasing from 0% to 40%) content of rapeseed oil.

Table 2
The results of admittance measurements (Y) of butter, fat mixes and rapeseed oil for selected frequencies of measuring voltage.

Selected frequencies	Admittance (mS)					Y_{100} (μS)	Significance of differences (0–40%)
	Y_0	Y_{10}	Y_{20}	Y_{30}	Y_{40}		
500 Hz	10.670[a]	10.568[a]	7.409[a]	6.111[a]	5.641[a]	0.009[a]	**
1 kHz	11.060[b]	10.789[b]	7.515[b]	6.262[b]	5.692[b]	0.022[b]	**
10 kHz	11.704[c]	11.159[c]	7.690[c]	6.500[c]	5.765[c]	0.269[c]	**
100 kHz	11.906[d]	11.159[c,C]	7.748[d]	6.572[d]	5.786[d]	2.776[d]	**
1 MHz	11.916[d]	11.272 [D,e]	7.703[e]	6.567[d]	5.767[ec]	31.334[e]	**

Y_0 – admittance of butter; Y_{100} – admittance of rapeseed oil.
$Z_{10–40}$ – admittance of fat mixes, the rapeseed oil content 10–40%.
[a,b,c,d,e] Significance of differences in columns, i.e. between impedance values obtained at particular (increasing) frequencies of the test voltage; upper small indexes – $\alpha \leqslant 0.01$, upper big indexes – $\alpha \leqslant 0.05$.
** Significance of differences in rows, i.e. between impedance values in fat mixes of different (increasing from 0% to 40%) content of rapeseed oil.

Table 3
The results of parallel equivalent capacitance measurements (C_p) of butter, fat mixes and rapeseed oil for selected frequencies of measuring voltage.

Selected frequencies (Hz)	Parallel equivalent capacitance (μF)					$C_{p\ 100}$ (pF)	Significance of differences (0–40%)
	C_{p0}	C_{p10}	C_{p20}	C_{p30}	C_{p40}		
20	28.332[a]	24.608[a]	17.522[a]	18.490[a]	10.190[a]	2.318[a]	**
40	14.322[b]	9.898[b]	8.218[b]	6.987[b]	3.824[b]	1.806[a]	**
80	6.172[c]	3.738[c]	3.290[c]	2.450[c]	1.346[c]	2.301[a]	**
100	4.589[d]	2.710[d]	2.394[d]	1.732[d]	0.952[d]	2.352[a]	**
500	0.452[e]	0.251[e]	0.204[e]	0.137[e]	0.072[e]	2.741[a]	**

$C_{p\ 0}$ – parallel equivalent capacitance of butter; $C_{p\ 100}$ – parallel equivalent capacitance of rapeseed oil, $C_{p\ 10–40}$ – parallel equivalent capacitance of fat mixes, the rapeseed oil content 10–40%.
[a,b,c,d,e] Significance of differences in columns, i.e. between impedance values obtained at particular (increasing) frequencies of the test voltage; small letters – $\alpha \leqslant 0.01$.
** Significance of differences in rows, between impedance values in products with different (increasing from 0 to 40%) content of rapeseed oil.

Table 4
The results of measurements of quality factor (Q_p) of butter, fat mixes, and rapeseed oil for selected frequencies of measuring voltage.

Selected frequencies (Hz)	Quality factor of butter, fat mixes, and rapeseed oil					Q_{p100}	Significance of differences (0–40%)
	Q_{p0}	Q_{p10}	Q_{p20}	Q_{p30}	Q_{p40}		
20	0.851[a]	0.794[a]	0.443[a]	0.454[a]	0.290[a]	−6.303[A,d,f]	**
40	0.585[b]	0.523[b]	0.300[b]	0.290[b]	0.196[b]	9.455[B,d]	**
80	0.394[c]	0.339[c]	0.204[c]	0.185[c]	0.129[c]	−49.268[C,d]	**
100	0.346[d]	0.295[d]	0.180[d]	0.160[d]	0.113[d]	1794.098[d]	**
500	0.137[e]	0.106[e]	0.075[e]	0.059[e]	0.040[e]	−113.848[d,e]	**

$Q_{p\ 0}$ – Quality factor of butter; $Q_{p\ 100}$ – Quality factor of rapeseed oil.
$Q_{p\ 10–40}$ – Quality factor of fat mixes from 10% to 40% content of rapeseed oil.
[a,b,c,d,e] Significance of differences in columns, between impedance values obtained at particular (increasing) frequencies of the measuring voltage; upper small indexes – $\alpha \leqslant 0.01$.
** Significance of differences in rows, i.e. between impedance values in fat mixes of different (increasing from 0% to 40%) content of rapeseed oil.

measured parameters in the function of frequency were observed for butter and the greatest for oil, respectively.

3.4. Regression equations of rapeseed oil content of fat mixes

The correlation analysis of rapeseed oil content in the function of changes in conductance parameters (Z,Y) of fat mixes demonstrated that at a significance level of $\alpha \leqslant 0.01$ and a correlation coefficient of $-0.954 < r < -0.983$, mathematical correlations occurred between the content of rapeseed oil in the mixes examined and Z and Y values, in a measuring voltage frequency range of 500 Hz to 2 MHz. Higher coefficients of correlation ($0.973 < r < 0.983$) were achieved for mathematical correlations between rapeseed oil content and Z values of the investigated mixes, compared to their Y values, ($-0.954 < r < -0.968$) – Table 5.

The correlation analysis of rapeseed oil content in the function of changes in capacitance parameters (C_p Q_p) of fat mixes demonstrated that at a significance level of $\alpha \leqslant 0{,}01$ and a correlation coefficient of $-0.950 < r < -0.990$, mathematical correlations existed between rapeseed oil content of the fat mixes and C_p and Q_p values, in a frequency range of 20– 500 Hz. Higher coefficients of correlation ($-0.950 < r < -0.990$) were achieved for the mathematical correlations between oil content and Q_p values than between oil content and C_p values ($-0.955 < r < -0.976$) of the fat mixes examined (Table 6). No mathematical correlations were obtained between the content of rapeseed oil in fat mixes and values of series equivalent capacitance (C_s) and quality factor (Q_s).

The performed correlation analyses of the rapeseed oil content in the function of conductance and capacitance parameters of butter and fat mixes showed that the strongest dependences were obtained between the oil content in studied mixes and their Q_p values at the frequency of 500 Hz. This means that the rapeseed oil content (C_{RO}) in fat mixes can be determined the most accurately on the basis of Q_p measurements and calculations by using the mathematical equation $C_{RO} = -407.562 \pm 33.861 \times Q_p + 53.990 \pm 3.054$, at $r = -0.990$ and $\alpha \leqslant 0.001$ (Table 6).

Based on the analysis of measurement results and based on the regression analysis of rapeseed oil content in the function of changes in conductance parameters (Z,Y) of fat mixes and butter it was observed that the contents of rapeseed oil calculated based on equations presented in Table 5 were the most similar to the assumed values, adopted as real values, at the frequencies of 1 MHz

Table 5
Regression analysis of rapeseed oil content (C_{RO}) in the function of impedance (Z) and admittance (Y) of fat mixes.

Frequency	Measured parameters	r	α	Regression equations
500 Hz	Z	0.973	0.000**	$C_{RO} = 0.400 \pm 0.055 \times Z - 32.858 \pm 7.478$
	Y	−0.954	0.000**	$C_{RO} = -6.263 \pm 1.143 \times Y + 70.604 \pm 9.56$
1 kHz	Z	0.977	0.000**	$C_{RO} = 0.401 \pm 0.051 \times Z - 31.992 \pm 6.775$
	Y	−0.958	0.000**	$C_{RO} = -6.015 \pm 1.038 \times Y + 69.706 \pm 8.890$
10 kHz	Z	0.982	0.000**	$C_{RO} = 0.400 \pm 0.045 \times Z - 30.388 \pm 5.860$
	Y	−0.964	0.000**	$C_{RO} = -5.615 \pm 0.899 \times Y + 68.084 \pm 8.005$
100 kHz	Z	0.982	0.000**	$C_{RO} = 0.399 \pm 0.044 \times Z - 29.838 \pm 5.654$
	Y	−0.968	0.000**	$C_{RO} = -5.489 \pm 0.865 \times Y + 67.533 \pm 7.794$
1 MHz	Z	0.983	0.000**	$C_{RO} = 0.397 \pm 0.043 \times Z - 29.692 \pm 5.639$
	Y	−0.964	0.000**	$C_{RO} = -5.469 \pm 0.867 \times Y + 67.279 \pm 7.801$

Note: C_{RO} – rapeseed oil content; r – correlation coefficient; α – significance level, calculated.
** Significance of differences ($\alpha \leqslant 0.01$).

Table 6
Regression analysis of rapeseed oil content (C_{RO}) in the function of parallel equivalent capacitance (C_p) and quality factor (Q_p) of fat mixes.

Frequency (Hz)	Measured parameters	r	α	Regression equations
20	C_p	−0.960	0.000**	$C_{RO} = -2.173 \pm 0.367 \times C_p + 63.080 \pm 7.625$
	Q_p	−0.950	0.000**	$C_{RO} = -61.730 \pm 11.743 \times Q_p + 54.962 \pm 7.125$
40	C_p	−0.976	0.000**	$C_{RO} = -3.986 \pm 0.511 \times C_p + 54.481 \pm 4.761$
	Q_p	−0.961	0.000**	$C_{RO} = -91.184 \pm 15.218 \times Q_p + 54.523 \pm 6.192$
80	C_p	−0.962	0.000**	$C_{RO} = -8.460 \pm 1.386 \times C_p + 48.757 \pm 5.213$
	Q_p	−0.971	0.000**	$C_{RO} = -137.957 \pm 19.804 \times Q_p + 54.508 \pm 5.331$
100	C_p	−0.959	0.000**	$C_{RO} = -11.1498 \pm 1.900 \times C_p + 47.599 \pm 5.240$
	Q_p	−0.974	0.000**	$C_{RO} = -157.889 \pm 21.390 \times Q_p + 54.522 \pm 5.035$
500	C_p	−0.955	0.000**	$C_{RO} = -104.450 \pm 18.681 \times C_p + 43.306 \pm 4.818$
	Q_p	−0.990	0.000**	$C_{RO} = -407.562 \pm 33.861 \times Q_p + 53.990 \pm 3.054$

Note: C_{RO} – rapeseed oil content; r – correlation coefficient; α – significance level, calculated;
** Significance of differences ($\alpha \leqslant 0.01$).

Table 7
Results of control measurements of impedance (Z) and admittance (Y) for fat mixes of different rapeseed oil contents at the optimum frequencies (f) of measuring voltage.

Reference content of rapeseed oil (%)	Z, f = 1 MHz		Y, f = 100 kHz	
	Measured value (Ω)	Calculated oil content (%)	Measured value (mS)	Calculated oil content (%)
6	91.05	6.45	11.00	7.15
9	98.15	9.27	10.52	9.79
15	112.90	15.13	9.50	15.39
18	120.05	17.97	8.99	18.19
22	130.00	21.92	8.31	21.92
27	142.00	26.68	7.46	26.59
33	156.80	32.56	6.42	32.29
36	164.00	35.42	5.94	34.93

Table 8
Results of control measurements of parallel equivalent capacitance (C_p) and quality factor (Q_p) for fat mixes of different contents of rapeseed oil at the optimum frequencies (f) of measuring voltage.

Reference content of rapeseed oil (%)	C_p, f = 40 Hz		Q_p, f = 500 Hz	
	Measured value (μF)	Calculated oil content (%)	Measured value	Calculated oil content (%)
6	12.00	6.65	0.118	5.90
9	11.23	9.72	0.110	9.16
15	9.82	15.34	0.096	14.86
18	9.14	18.05	0.089	17.72
22	8.20	21.80	0.080	21.79
27	6.97	26.70	0.067	26.68
33	5.50	32.56	0.051	33.20
36	4.82	35.27	0.045	35.65

(Z) and 100 kHz (Y) – Table 7. In turn, based on the analysis of measurement results and based on the regression analysis of rapeseed oil content in the function of changes in capacitance parameters (C_p,Q_p) of fat mixes and butter it was observed that the contents of rapeseed oil computed based on equations presented in Table 6 were the most similar to the real values at the frequencies of 40 Hz (C_p) and 500 Hz (Q_p) – Table 8.

Taking this into account, control studies were conducted at the above-mentioned frequencies to measure the electrical parameters of the mixes with contents of rapeseed oil different than in the basic study.

Results of those studies demonstrated that the content of rapeseed oil in fat mixes, calculated based on measurements of conductance and capacitance parameters and equations presented in Table 5 and 6, were the closest to the assumed (real) values in oil content range of 10–30%, however the most similar to the real values were the values calculated based on regression equations for oil content in the function of changes in Q_p values. In addition, it was observed that the contents of rapeseed oil in fat mixes computed based on those equations were the closest to the real value in the entire range of oil content (0–40%). It indicates that the content of rapeseed oil (C_{RO}) in fat mixes may be determined the most precisely based on its regression equations in the function of changes in Q_p values (Tables 7 and 8).

The highest correlations between rapeseed oil content of the fat mixes examined and Q_p values, at the frequency of 500 Hz, and a lack of a significant correlation between oil content of the fat mixes and C_s values substantiate the selection of the RCC model for studies of their electrical properties. This has also been demonstrated in our another study (Żywica et al., 2012) into the determination of correlations between fat content of raw milk and its electrical properties. This model was also applied by Mabrook and Petty 2003a,b, to assay the chemical composition of milk and degree of its dilution with water. Changes in the RCC model compared to the RRC model consist in substituting parallel resistance R_p (RRC model) with parallel capacitance C_p (RCC model), and in analyzing such biological systems as butter or fat mixes based on capacitance parameters linked with their electrical properties, particularly with their dielectrical properties. However, complete elucidation of this problem requires further investigations that are currently in progress.

The relationships presented in the manuscript are described with linear equations and enable us to determine precisely the rapeseed oil content in fat mixes. These relationships result from the addition of rapeseed oil, which is a strong dielectric [Z = 0,05–119.988 MΩ; Y = 0.009–31.334 μS (Tables 1 and 2)], to butter, which has a considerably weaker dielectric properties [Z = 82.927–92.513 Ω; Y = 10.670–11.916 mS (Tables 1 and 2)]. The oil-containing fat mixes have gradually stronger dielectric properties. The differences between dielectric properties of butter and rapeseed oil are probably related to a various content of long-chain saturated, monounsaturated and polyunsaturated fatty acids in studied products as well as lack of short-chain fatty acids in rapeseed oil which in turn probably to the utmost degree influence electric properties (conductance properties, especially) of the studied fat mixes. To confirm this supposition, however, the effect of chemical composition of vegetable oils on their electric properties has to be studied, which we are going to do in a short time.

4. Conclusions

1. Results of measurements of conductance and capacitance parameters of fat mixes, with the addition of rapeseed oil, and butter as well as statistical calculations demonstrated explicitly that their values and changes depended on the percentage content of oil and on the frequency of measuring voltage, with the greatest changes being observed as a result of measurements and calculations of capacitance parameters.
2. Mathematical correlations between rapeseed oil content in fat mixes and values of impedance (Z) and admittance (Y) point to the feasibility of applying measurements of those parameters for the determination of the percentage content of oil in the investigated fat mixes in the entire examined range of measuring voltage frequency. Mathematical correlations between rapeseed oil content and values of parallel equivalent capacitance (C_p) and quality factor (Q_p) indicate the feasibility of using measurements of those parameters to determine rapeseed oil content of fat mixes in a frequency range from 20 to 500 Hz.
3. The presented results of measurements and statistical calculations form grounds for further investigations into predicting the content of rapeseed oil and other vegetable oils in fat mixes and into detecting their adulterations based on electrical conductance (Z,Y) and capacitance (C_p,Q_p) parameters, but still more useful and advisable to this end, though more difficult to perform, are measurements of capacitance parameters, quality factor (Q_p) in particular.

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