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

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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.

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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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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).

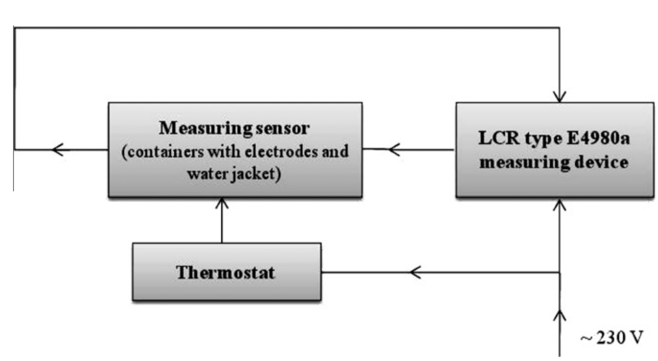

Fig. 1. Scheme of measurement system for electrical properties examination of butter and fat mixes.

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