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A new method to measure fat content in coconut milk based on Y-type optic fiber system

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ABSTRACT

This paper presents a new method of measuring fat content in coconut milk at room temperature (25 °C) based on the designed Y-type optical fiber measurement system and makes the analysis and evaluation of this system. The system consists of light source, Y-type optical fiber, signal amplification module, signal conversion module and microprocessor module. The new method of assessing the accuracy of the measurement system – R&R (Repeatability and Reproducibility) assessment method is introduced here. It makes the effective analysis and evaluation and judges the reliability of the Y-type optical fiber system, laying the foundation for obtaining high quality data. The results show that the designed measurement system has high precision and can satisfy the measurement of this kind of samples.

1. Introduction

Coconut milk is a natural plant protein drink which tastes mellow and is suitable for people of all ages. It is a milky white oil in water emulsion extracted from the gratings of coconut with or without addition of water [1,2]. And also it plays an important role in many tropical cuisines, most notably those of Southeast Asia, as well as Brazilian, Indian and Polynesian cuisines [3]. Fresh coconut milk has the functions of replenishing spleen, insecticidal eliminate rickets and moisturize the skin and has various uses [4–6]. And for the high production and rich source of coconut milk, it is of great utilization value [7]. To extend the shelf-life, coconut milk has been processed in many forms such as canned coconut milk.

Coconut milk contains fat, water, carbohydrate, protein and ash with the major components being water and fat. It is a fat rich liquid with varying contents of fat depending on the method of extraction of coconut milk and addition of water [8]. While coconut milk is high in saturated fat (17%), it is much healthier than other saturated fat products, and the fat is easily metabolized by the body [9,10]. Previous research works have demonstrated that fat particle size had significant effects on a stability of foods containing high fat content such as milk, yourt and cheese [11,12]. Simuang et al. examined the effects of temperature (70–90 °C) and fat content (15–30%) on the flow properties of coconut milk [13]. They stated that fat globules tended to form cluster at high temperature which resulted in the changes of rheological properties of coconut milk. And then Tangsuphoom and Coupland [14] and Thitima and Chiewchan [15] also demonstrate that fat content and stabilizing agent have significant effect on the flow behavior of coconut milk. Tansakul and Chaisawang investigated the effects of fat content and temperature on the thermophysical properties. It was concluded that a decrease in fat content of coconut milk samples and an increase in temperature resulted in an increase in values of thermal properties. In addition, the influence of fat content on thermal properties of coconut milk was stronger than that of temperature [16]. Many factors have been reported to affect the stability of oil in water emulsion including processed coconut milk, such as fat content [17,18].

Fat is one of the main components of food. Food have more physiological heat with more fat content. Fat content of coconut milk affects not only the flavor, but also the shelf life. So manufacturers strictly control the fat content in a certain range. A lot of methods are used to measure fat content, such as Soxhlet method, saponification method and ether extraction method. For milk and its products, the Rose–Gottied rule is a standard method. As coconut milk has the similar physical and chemical properties with milk products, production enterprises and inspection departments have adopted this method to measure the fat content in coconut milk. For the determination of total fat, the solvent extraction methods are widely used such as direct solvent extraction technique for butter and spreadable fat, acid hydrolysis–solvent extraction technique [19] for flour, sea foods and alkaline hydrolysis–solvent

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extraction technique (Roese–Gottlieb) for milk and cream. Non-solvent extraction method for raw milk, Babcock method, Gerber method and instrumental methods such as IR and NMR [20] are also known such as for milk. Given the fat importance on the properties and other aspects of coconut milk, it is surprising that very few indepth studies have been reported so far on the measurement of fat content in coconut milk. Lakshanasomya et al. aimed to establish methods and to conduct the method performance study on determination of total solids and total fat in coconut milk and products [21]. Those methods are, however, very difficult and time and solvent-consuming, and, because they involve long and complex procedures, are unsuitable for routine analysis [22,23]. Therefore, a fast and simple method to measure fat content in coconut milk is very necessary.

This paper presents a new method to measure the fat content of coconut milk based on Y-type optical fiber measurement system. The designed hardware consists of light source, detector, TEC control module, Y-type optical fiber, preamplifier and second-level amplifier, A/D converter and other components. Assessing the stability and linearity of the system and analyzing how much the variation caused by measurement system accounts for total variations by the method of R&R ensure that the main sources of variation come from the process itself rather than the measurement system and the capability of measurement system can meet the requirements of measurement process. The Y-type optical fiber measurement system used here has high precision, and can detect such kind of samples. This will increase the production and promotion of the coconut industry.

2. Modeling principle

Based on diffuse reflectance measurement, we introduce several parameters of diffuse reflectance spectrum. K is the absorption coefficient of diffuse reflectance material, which depends on the chemical composition of the sample. S is the scattering coefficient, which depends on the physical properties of diffuse reflector. R is the diffuse reflectance, which reflects the ratio of the incident light and the exit light. The relationship among R, K and S is expressed as:

$$R = 1 + \frac{K}{S} - \left[\left(\frac{K}{S}\right)^2 + 2\left(\frac{K}{S}\right)\right]^{1/2} \tag{1}$$

R is a function of (K/S), and has nothing to do with the absolute value of K or S. As R is not easily to be measured, we always measure the relative diffuse reflectance. In other words, an non-absorbent material is used as a reference in the near infrared region. This reduces the influence of regular reflection and eliminates the spectral characteristics of the instrument. As the scattering coefficient of BaSO4 is about 1 and the absorption coefficient is about 0, we can figure out the relative diffuse reflectance R_∞ of the sample when its thickness is infinity:

$$R_\infty = \frac{R_{sample}}{R_{ref}} \approx 1 + \frac{K}{S} - \left[\left(\frac{K}{S}\right)^2 + 2\left(\frac{K}{S}\right)\right]^{1/2} \tag{2}$$

The relative diffuse reflectance can be obtained by following method. The standard whiteboard ($BaSO_4$) is figured as reference, R_∞ and we measure its output voltage value of the amplification module (V_{ref}) of diffuse reflection light intensity. Then, we measure the output voltage value (V_{sample}) of diffuse reflection light intensity of the sample. Then the relative diffuse reflectance R_∞ can be obtained by calculating the ratio of them:

$$R_\infty = \frac{V_{\mathrm{sample}}}{V_{\mathrm{ref}}}. \tag{3}$$

Table 1
Nutrition composition of coconut milk.

Nutrition composition	Content per 100 ml of coconut milk
Protein	0.6 g
Fat	1.8 g
Carbohydrate	7.0 g
Na	10 mg

Similarity to the absorbance of transmission spectrum, the definition of the absorbance of diffuse reflectance is defined as:

$$A = -lg(R_\infty) = -lg\left(\frac{V_{\mathrm{sample}}}{V_{\mathrm{ref}}}\right) = -lg\left\{1 + \frac{K}{S} - \left[\left(\frac{K}{S}\right)^2 + 2\left(\frac{K}{S}\right)\right]^{1/2}\right\} \tag{4}$$

Obviously, the relationship between A and K/S is a logarithmic curve. But it can be expressed as a straight line when the value of K/S is in a certain range:

$$A = a_0 + b_0\frac{K}{S} \tag{5}$$

The research of tissue optics shows that wavelength near 1060 nm, the absorption coefficient and the fat content is linear [24]. For the sample with only one component, the absorption coefficient K is proportional to the sample concentration C when the concentration is low:

$$K = \varepsilon C. \tag{6}$$

where ε is the molar coefficient [25]. After adding EDTA ($C_{10}H_{16}N_2O_8$) in the coconut milk, the scattering coefficient of the sample is only related to the size of fat particle. By homogenizing the sample, the scattering coefficient S can remain unchanged [26]. Therefore, Eq. (5) can be rewritten as:

$$A = a_1 + b_1 C_p. \tag{7}$$

Another form can be obtained as:

$$C_p = kA + b \tag{8}$$

In Eq. (8), A is the absorbance of sample which can be calculated by Eq. (4). C_p is the fat content in coconut milk after adding EDTA. k and b are the coefficients of Eq. (8). Therefore, Eq. (8) can be used as the modeling theoretical basis.

3. Samples and method of measurement

3.1. Samples

A tin of coconut milk (245 ml) bought from a local market was used in the experiments. For typical canned coconut milk, its nutrition composition is shown in Table 1, where fat is 1.8 g in per 100 ml coconut milk.

Fat and protein particles have larger size than other substances in the coconut milk. Therefore, these two components contribute to the scattering light. As we want to measure one component, the other component has to be dissolved into small molecules.

The fat content of coconut milk C and C_p can be expressed as:

$$C = \frac{m_{\mathrm{fat}}}{m_{\mathrm{coconut}} + m_{\mathrm{water}}} \tag{9}$$

$$C_p = \frac{m_{\mathrm{fat}}}{m_{\mathrm{coconut}} + m_{\mathrm{EDTA}} + m_{\mathrm{water}}} \tag{10}$$

where C represents the fat content after adding distilled water. C_p represents the fat content after adding EDTA solution and