MOISTURE LOSS MODELS OF SWEET POTATO, CASSAVA AND TARO DURING FRYING

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ABSTRACT

Sweet potato, cassava and taro were cut into stick (0.01 x 0.01 x 0.05 m) and deep fat fried at three temperatures (160, 170 and 180 ºC) for 0 to 360 s. The effects of these cooking methods on moisture loss characteristics were evaluated. The rapid moisture loss from the sticks within the first 100 s of deep fat frying followed by considerably reduced rates. Moisture diffusivity in sweet potato, cassava and taro sticks were evaluated using analytical solution of Fick's second law diffusion equation. Moisture diffusivities were ranging from 1.43×10^{-8} to 1.99×10^{-8} m^2/s, 1.38×10^{-8} to 2.25×10^{-8} m^2/s, and 3.08×10^{-8} to 5.25×10^{-8} m^2/s respectively, at temperatures ranging from 160 to 180 ºC, for sweetpotato, cassava and taro. Corresponding activation energies for moisture transfer were 26.88; 39.61 and 43.51 kJ/mol for sweet potato, cassava and taro deep fat frying, respectively.

Keywords: Modeling, moisture loss, frying, sweet potato, cassava, taro

INTRODUCTION

Sweet potato, cassava and taro are tuberous crops cultivated in Indonesia and considered as source of carbohydrates. These types of tubers usually consumed after boiling, steaming, frying, or may be sliced into chips, powdered into flour or pounded into puree. Frying is the preferred way to consume these tubers.

Frying is one of the oldest methods known to human kind for preparing foods. Fried foods are among favorites for people around the world. During frying process, heat is transferred from the hot oil to the surface of the food material, while moisture is transferred from the interior to the surface. As a result, high temperature and low moisture conditions are developed as frying proceeds, and bring about the desirable characteristics (color, texture, and flavor) of food product.

Designing of frying processes is possible through the use of mathematical models. Banga *et al.* (1993) stated that a reliable simulation of the process using mathematical model is essential for process optimization and control. An accurate heat and moisture transfer parameter are important for modeling processes during which simultaneous heat and moisture transfers take place.

The objectives of this work were therefore to develop the mathematics models approach for determining water loss during frying of sweet potato, cassava and taro sticks.

MATERIAL AND METHODS

Sample Preparation

Sweet potato var. Sukuh, cassava and taro were peeled, washed and cut by using manually operated cutting device into stick of 0.01 m x 0.01 m x 0.05 m. The uniformity of thickness was checked using caliper (Mitutoyo, Japan).

Frying

Experiments were carried out in a temperature controlled frying unit of 2.0 l oil capacity at 160, 170 and 180 ºC respectively, using oil as frying medium. Sweet potato, cassava and taro sticks were fried for 360 s and removed from the frying unit at 60 s intervals.

Sample Analysis

Sweet potato, cassava and taro sticks were separated on moisture analysis. Moisture content was determined according to the AOAC standard method.

Modeling Moisture Loss and Diffusivity

Mass transfers for frying product, such as sweet potato, cassava and taro, can be assumed that it were equal to mass transfer in a single grain. The particle were generally small, so the mass transfer flux in the sweet potato, cassava and taro sticks were considered as negligible. The mass transfer flux in the stick was considered as negligible, the first term solution of diffusion equation for the frying product can be obtained according to the Crank (1975) with the following assumptions: an infinite slab geometry, shrinkage is negligible, initial moisture content of the stick was uniform, uniform initial moisture content and negligible external mass transfer resistance. At this conditions, mass transfer in sweet potato, cassava and taro stick can be modeled using the Fick's second law of diffusion equation as given in Equation 1.

$$\frac{\delta M}{\delta t} = D_e \frac{\delta^2 M}{\delta x^2} \qquad (1)$$

Where M is the instaneous moisture content, t is time, De is effective moisture diffusivity and x is position coordinate in the product.

$$\frac{M - M_e}{M_o - M_e} = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 Dt}{4L^2}\right) \qquad (2)$$

Where M_o and M_e are the initial and equilibrium moisture content respectively, and L is the thickness of the breading. It has been considered in Equation 2 that moisture flux at the stick interface is negligible. Accordingly, moisture content at a given time can be expressed as follows:

$$M = \frac{8}{\pi^2}(M_o - M_e)\exp\left(-\frac{\pi^2 Dt}{4L^2}\right) + M_e \qquad (3)$$

A non linear regression approach was used to estimate best fit moisture diffusivity. Temperature dependency of diffusivity was determined using the Arrhenius expression:

$$D = D_o \exp\left(\frac{E_a}{RT}\right) \qquad (4)$$

Where D_o is the frequency factor, E_a is the activation energy, R is the gas constant and T is temperature of frying or baking in absolute unit.

RESULTS AND DISCUSSION

The effects of temperature and time on moisture loss of sweet potato, cassava and taro sticks were statistically significant ($p < 0.05$). The moisture content of sweet potato, cassava and taro sticks during frying shown in Figure 1. Its were rapid decreases on moisture content of sweet potato, cassava and taro sticks within the first 100 s of frying followed by reduced constant rate moisture loss. The moisture profile in sweet potato, cassava and taro sticks are typical of moisture loss during frying at high temperatures (Budzaki and Seruga, 2005; Krokida *et al.*, 2000; Moreira *et al.*, 1997; and Gamble *et al.*, 1987). Heat is transferred from the heating medium (frying oil) to the surface of the sticks. Farkas *et al.* (1996) identified four stages of frying namely initial heating of the product surface to the medium temperature, surface boiling, falling rate and bubble end point. Although these stages are not easy to delineate, it is clear that the first stages may have occurred at the surface of the sweet potato, cassava and taro sticks within 100 s of frying.

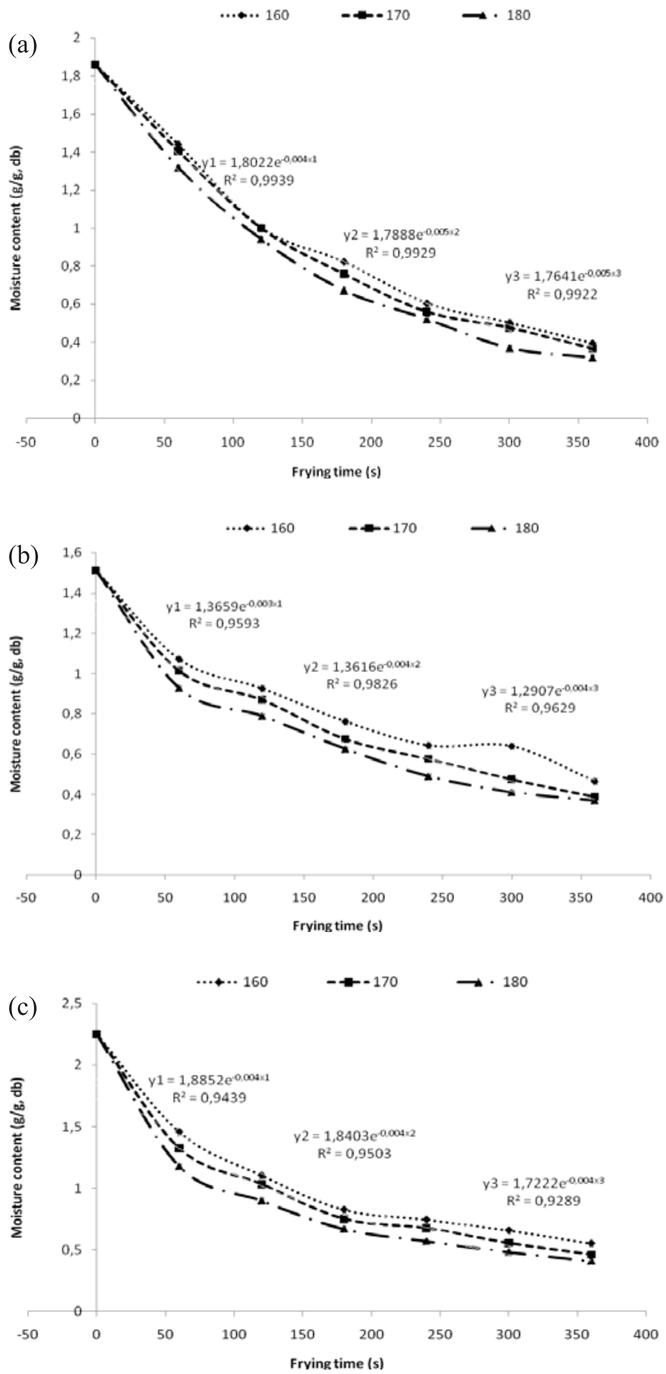

Figure 1. Moisture content profiles of sweet potato (a), cassava (b), and taro (c) sticks during frying.

Moisture loss is the major mass transport phenomenon that takes place during frying. Deep-fat frying causes drying of food products. Predicting water loss is very vital in modeling and controlling deep fat frying operations. From Equation 3, moisture on the sweet potato, cassava and taro sticks can be expressed as follows:

$$M = A_1 \exp(A_2 t) + A_3 \tag{5}$$

where A_1, A_2 and A_3 are regression constants that were obtained from experimental data. The Fick's diffusion equation adequately predicted moisture loss in the sweet potato, cassava and taro sticks during deep fat frying processes.

Tabel 1. Model parameters for moisture transfer in sweet potato, cassava and taro sticks.

Kind of tuber	Stick moisture model* parameters			R^2
	A_1	A_2	A_3	
Sweet potato				
160ºC	0.0473	-0.00141	1.802	0.994
170ºC	0.0582	-0.00158	1.789	0.993
180ºC	0.0781	-0.00196	1.764	0.992
Cassava				
160ºC	0.1195	-0.00136	1.366	0.959
170ºC	0.1229	-0.00172	1.362	0.983
180ºC	0.1805	-0.00222	1.291	0.963
Taro				
160ºC	0.2955	-0.00303	1.885	0.944
170ºC	0.3319	-0.00372	1.840	0.950
180ºC	0.4277	-0.00518	1.722	0.929

*$M = A_1 \exp(A_2 t) + A_3$

Values of moisture diffusivity obtained in this study ranged from 1.43x10^{-8} to 1.99x10^{-8} m^2/s, 1.38x10^{-8} to 2.25x10^{-8} m^2/s, and 3.08x10^{-8} to 5.25x10^{-8} m^2/s for sweet potato, cassava and taro stick's during frying, respectively, at temperatures ranging from 160 to 180 ºC. Yildiz *et al.* (2007) reported moisture diffusivity ranging from 9.2x10^{-9} to 18.2x10^{-9} m^2/s for frying of potato slices at temperatures from 150 to 190 ºC. Indira *et al.* (1999) reported effective moisture diffusivities ranging from 2.62x10^{-8} to 3.42x10^{-8} m^2/s for the casing part of samosa (a product consisting of stuffed vegetable core and an outer casing made of wheat flour dough) during deep fat frying at temperatures from 155 to 185 ºC. Baik and Mittal (2005); Ngadi and Correira (1995) and Ngadi *et al.* (2006) obtained lower values of moisture diffusivity ranging from 8.2x10^{-10} to 11.9x10^{-10} m^2/s; 13x10^{-10} to 16.4x10^{-10} m^2/s; and 20.93x10^{-10} to 29.32x10^{-10} m^2/s, for deep fat frying of tofu at 147 to 172ºC; chicken muscles at 120 to 180 ºC; and chicken nugget at 150 to 190 ºC, respectively. The differences in reported moisture diffusivity values are obviously due to the intrinsic differences in product properties and frying temperature ranges.

The temperature dependency of moisture diffusivity was modeled using the Arrhenius equation as given in Equation 6, 7 and 8; for sweet potato, cassava and taro sticks during frying, respectively.

$$\ln D = -\frac{3232.9}{T} - 10.614;\ (R^2 = 0.967) \tag{6}$$

$$\ln D = -\frac{4764.5}{T} - 7.0981;\ (R^2 = 0.998) \tag{7}$$

$$\ln D = -\frac{5233.6}{T} - 5.2324;\ (R^2 = 0.977) \tag{8}$$

The activation energies were 26.88; 39.61 and 43.51 kJ/mol for sweet potato, cassava and taro frying, respectively. Yildiz *et al.* (2007) reported the activation energies for potato slices during frying was 27.6 kJ/mol (R^2 = 0.931), which falls within the range of activation energies reported by McMinn and Magee (1996) for drying of potato cylinders (25.2 – 36.2 kJ/mol). The activation energy obtained during frying were higher than 8.04 kJ/mol for deep-fat frying of chicken nuggets (Ngadi *et al.*, 2006), and 14.34 kJ/mol for deep-fat frying of samosa (Indira *et al.*, 1999). The higher activation energy may be attributed to the tighter binding of water molecules by the protein in the sweet potato, cassava and taro stick.

CONCLUSION

Moisture transfer was mostly from inside to the surface of sweet potato, cassava and taro sticks, especially during the early stages of deep fat frying. Thus moisture transfer in the stick were adequately modeled using Fick's equation with negligible mass flux at the stick interface. Moisture diffusivities were ranging from 1.43x10^{-8} to 1.99x10^{-8} m^2/s, 1.38x10^{-8} to 2.25x10^{-8} m^2/s, and 3.08x10^{-8} to 5.25x10^{-8} m^2/s for sweet potato, cassava and taro stick's during frying, respectively, at temperatures ranging from 160 to 180 ºC. Corresponding activation energies for moisture transfer were 26.88; 39.61 and 43.51 kJ/mol for sweet potato, cassava and taro deep fat frying, respectively.

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