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Drying kinetic modelling of dried black potato (*Plectranthus rotundifolius*) cultivated in Indonesia

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Abstarct. The drying kinetic modelling of dried black potato (Plectranthus rotundifolius) was studied by employing electrical cabinet oven. The parameter investigated was moisture content, regarding to the drying temperature (70, 80 and 90 ºC) and slice thickness (2, 3 and 4 mm). The lowest sum square error of drying kinetic model (0.0014) was obtained by applying logarithmic model of thin layer drying. This value performed by 4 mm of slice thickness of black potato with 80 °C of drying temperature during 195 min of drying time. This result indicated that the logarithmic model is the most suitable model for interpreting the thin layer drying kinetic of black potato.

1. Introduction

Black potatoes are a type of tuber in the same group as potatoes and are classified in the lamiceae family. It provides a potential food crop as an alternative food source, but cultivation in the community actually decreases increasingly scarce. *Plectranthus rotundifolius* is an erect, 30 cm tall of bushy, and semi-succulent stem of annual herb with a thick leaf. Plant grows well in poor or sandy soil with direct sunlight, moreover it is also tolerant of drought and rainfall [1]. The tubers can be harvested after 4 to 5 months flowering and the aerial parts of plant have died [2]. The selection of black potatoes as objects in this study is in line with the national strategic planning in the field of diversification of local resource-based food consumption with exploration of the utilization of non-conventional food crops, including tubers [3].

Black potato tubers contain more carbohydrates (33.7 gr/100 g) compared to yellow potatoes (13.4 gr/100 g). Energy in black potato tubers (400 cal) is even 6 times that of yellow potatoes (64 cal) [4]. Moreover, [5] also mentioned that black potato is rich in essential minerals and vitamins, in addition to low glycemic index of carbohydrate source. This carbohydrate source potentially developed as a nutritious functional food, due to the high content of ascorbic acid in the tuber [6].

Crispy snack derived from potato possibly served by applying fresh, slice or dough taste of potatoes. For obtaining potato chips, the process preparation includes the potato harvesting, selecting, storage before processing, peeling, slicing, frying or drying, applying flavour and packaging [7]. In order to

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result the identical colour of chips, therefore the tubers should be consistency sliced in thickness. Before drying or frying, any starch or other materials resulted from peeling and slicing fed into running water in order to clean the slices. Most of dry crisp snack are mass production, and therefore their initial and final structure and also texture are very concerned [8].

Potato chips with thin slices are mostly losing their moisture content more than 75 % and reaching around 2 % during processing. However, during the hot temperature contact of oil frying, unavoidably causing a substantial absorption of oil around 35 % and mostly located on the surface of the chip. It is indicated that there was poor hot oil penetration during frying and stuck in the surface at the end of frying [9]. The application of hot air during drying can be avoid this problem and resulted non-oily dried product. Therefore, this study investigated the drying process and the kinetic of black potato at 70, 80 and 90 °C, regarding the slice thickness of 4 mm.

2. Methodology

2.1. Drying treatment

An oven universal UN 110 produced by Memmert (Schwabach, Germany) was applied for determination of drying kinetics of black potatoes. The hot air produced by heating coil in the dryer cabinet was employed to determine the dry sample mass with temperature 70, 80 and 90 °C. The material thickness was 4 mm. The dried materials were weighed subsequently every 15 min until constants weight by using Ohaus PA 214 (NJ, USA).

2.2. Analysis of drying kinetics

The drying kinetics of different permeable materials are frequently observed by using thin-layer equations, which possibly divided into three groups (i.e. theoretical, semi-theoretical and empirical. The theoretical discuss about internal resistance to moisture transfer only, while the others discuss about the external resistance to moisture transfer between the product and the air only [10]. Among the semi-theoretical thin-layer drying models, the Lewis model (2), the Henderson and Pabis model (3) and the Two-term model, are used widely.

The Fick's second law applied by assuming that there is evenly distributed resistance of the moisture flow along with the homogeneous material and avoid the diffusion coefficient, D, of the local moisture content. If the decreasing of volume is neglected, the Fick's second law possibly re-writes as:

$$\frac{\partial M}{\partial t} = D\nabla^2 M \tag{1}$$

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp(-kt) \tag{2}$$

$$MR = \frac{M - M_e}{M_0 - M_e} = a\exp(-kt) \tag{3}$$

The empirical models explained a direct relationship between the moisture content obtained by experimental and the drying time. They avoid the basic theory of the drying process and there is no meaning on its parameter. Therefore, they gave an un-clear and inaccurate critical point of view during drying, although it describes the drying curve for the conditions of the experiment better than the semi-theoretical ones [11]. The empirical models studied in this work are including Logarithmic model (4), Two-term exponential model (5), Diffusion Approach model (6), and Modified Henderson and Pabis model (7).

$$MR = a\exp(-kt) + c \tag{4}$$

$$MR = a\exp(-kt) + (1-a)\exp(-kat) \tag{5}$$

$$MR = a\exp(-kt) + (1-a)\exp(-kbt) \tag{6}$$

$$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-ht) \qquad (7)$$

All of the kinetic data obtained by applying solver program included in Microsoft Excel 2010 Software.

3. Results and discussion

Figure The drying kinetics of black potato tubers were studied by plotting the experimental data into the semi-theoretical thin-layer drying models and the empirical models. The semi-theoretical thin-layer drying models discussed are Lewis model, the Henderson and Pabis model and the Two-term model, the empirical models are Logarithmic model, Two-term exponential model, Diffusion Approach model, and Modified Henderson and Pabis model.

3.1. Modeling of the drying kinetics

Figure 1 presents the concept of drying processing of thin layer. M_0 indicated the initial mass of single chips, while M_e presented the equilibrium mass of single chips after t min of drying with x mm of thickness. T_s showed the surrounding temperature affected the chips and resulted to the heat (Q) absorbed by the chips. H_2O is indicating the amount of H_2O vaporized from the wet chips.

The assumptions applied during drying are (i) the chip is uniform; (ii) no alteration with the chip's characteristics and regardless to the shrinkage may occur; (iii) condition is isobaric; (iv) avoid the diffusion of water from internal porous and regarding only to the surface evaporation; (v) evenly the initial moisture contents of the chips and exactly similar parts facing each other while drying is occurring; (vi) the moisture equilibrium arises on the surface due to the finishing of surface diffusion; (vii) surrounding temperature is equals to the ambient drying air temperature, (viii) the heat transfer is done by conduction within the product, and by convection outside of the product; (ix) effective moisture diffusivity is constant versus moisture content during drying [12].
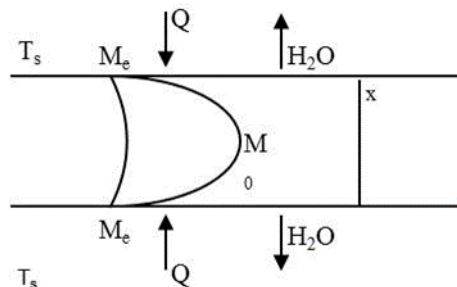

Figure 1. Drying mechanism of thin layer [12].

3.2. Comparison of experimental and calculated MR

The empirical value of each models showed on the table 1. Fig. 2 presents the effect of drying time on the moisture content of experimental data (symbol) and calculated data (line) of drying kinetics on 4 mm slice thickness of black potato, regarding to the drying temperature. It shows that Logarithmic (empirical approach) model and Henderson & Pabis (semi-theoretical approach) model gave excellent fit on the experimental data (less than 0.01 of SSE (sum square error) with exception of 90 °C of Henderson & Pabis). The lower value of SSE provided the better the fitting models of experimental data. The others model shows the value of SSE more than 0.01 which indicated the poor fitting experimental data on the model. The Logarithmic model provided better modelling than the Henderson & Pabis model, with the minimum value of SSE were obtained (less than 0.005). Since there were many negligible points of view on the empirical model, it shows that Henderson & Pabis provided more accounted calculated data for drying kinetic approach. The constant of c on the Logarithmic model provided the better accuracy on the fitting model while comparing to the Henderson & Pabis model.

Akpinar [19] found that other empirical model of Midilli or Thompson model [20] well explained the drying potato chips at 60–80 °C. Higher drying temperature provided the faster the lower moisture content obtained, however higher temperature also leads to the case hardening of the chips and therefore the browning colour of the surface.

Table 1. Drying kinetics of black potato on 4 mm slice thickness of chips.

Thin Layer Drying Model	Temperature (°C)	k	a	g	B	h	c	SSE
Lewis [13]	70	0.0176	-	-	-	-	-	0.1199
	80	0.0295	-	-	-	-	-	0.0501
	90	0.0285	-	-	-	-	-	0.0596
Henderson & Pabis [14]	70	0.0131	0.7447	-	-	-	-	0.0074
	80	0.0242	0.8098	-	-	-	-	0.0038
	90	0.0235	0.8117	-	-	-	-	0.0129
Logarithmic [15]	70	0.0112	0.7667	-	-	-	-0.0393	0.0020
	80	0.0220	0.8264	-	-	-	-0.0261	0.0014
	90	0.0179	0.8796	-	-	-	-0.0898	0.0039
Two-term exponential [16]	70	0.0176	1.000	-	-	-	-	0.1199
	80	0.0295	1.000	-	-	-	-	0.0501
	90	0.0285	1.000	-	-	-	-	0.0596
Diffusion approach [17]	70	0.0176	1.000	-	1.000	-	-	0.1199
	80	0.0295	1.000	-	1.000	-	-	0.0501
	90	0.0285	1.000	-	1.000	-	-	00596
Modified Henderson & Pabis [18]	70	0.0131	0.2482	0.0131	0.2482	0.0131	0.2482	0.0074
	80	0.0242	0.2699	0.0242	0.2699	0.0242	0.2699	0.0038
	90	0.0235	0.2706	0.0235	0.2706	0.0235	0.2706	0.0129

3.3. Effective diffusivity

The effective moisture diffusivity, D_e, is used to explain the moisture diffusion process during drying and calculated by using the method of Fick's second law. Its solution (presents as the diffusion of liquid in a slab shaped solid in terms of the dry basis moisture content) can be written as follows [21]:

$$MR = \frac{8}{\pi^2} \exp\left[-D_e\left(\frac{\pi}{Ht}\right)^2 t\right]$$

(8)

Rizvi [22] mentioned that the effective diffusivities are regarding to the uniformity of the material and the air temperature during drying, which commonly described by using the Arrhenius-type relationship [23, 24]. The natural logarithm of D_e as a function of the absolute temperature is plotted to show a linear relationship between (ln De) and (1/T) as shown at Fig. 3, leading to an Arrhenius-type relationship:

$$D_e = D_o \exp\left(\frac{-E_a}{RT}\right)$$

(9)

The slope of the straight line is (-Ea/R) from which the activation energy Ea is calculated for the drying process. The diffusivity constant D_0 is also calculated from the intercept of the straight line. The value of D_0 obtained is 1.258E-11 m2/s and the value of Ea is 3.23E-08 J/mol.
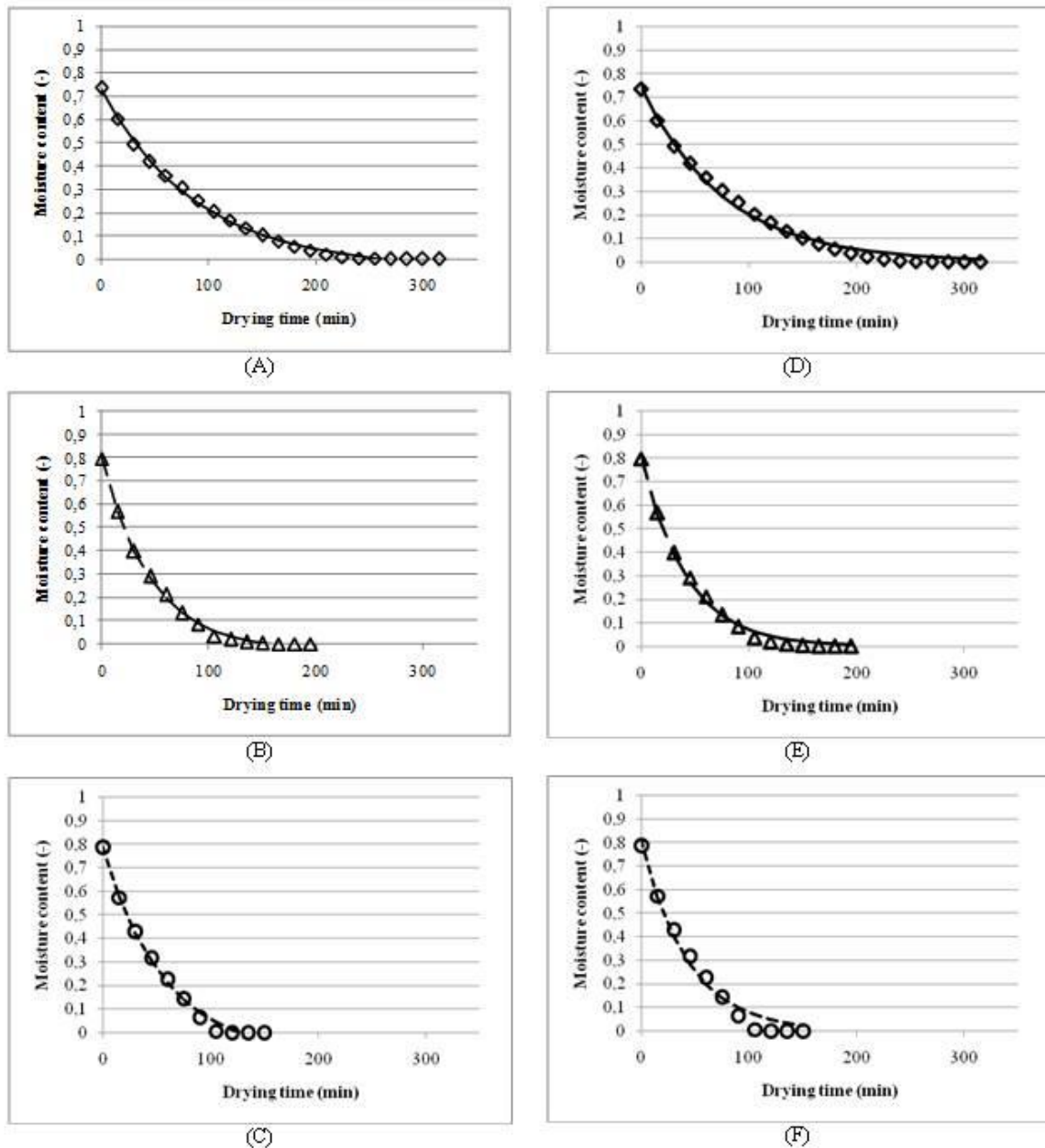

Figure 2. Plotting the drying time against the moisture content of experimental data (symbol) and calculated data (line) of drying kinetics on 4 mm slice thickness of black potato; Logarithmic model (A, B, C) and Henderson & Pabis model (D, E, F). Drying temperature: 70 (A, D), 80 (B, E) and 90 (C, F) °C.
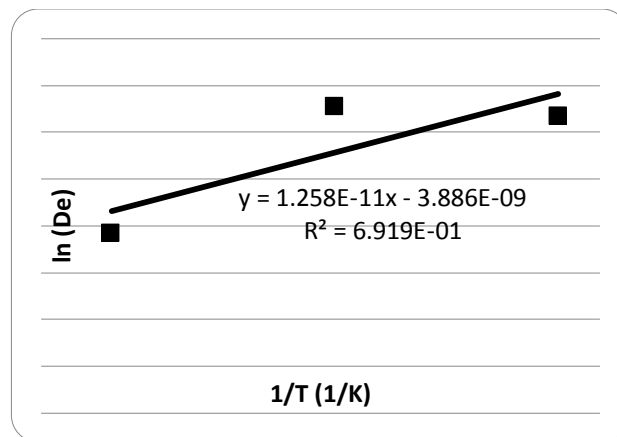
Figure 3. Arrhenius plot of effective diffusivity and temperature.

4. Conclusion

The lowest sum square error of drying kinetic model (0.14) was obtained by applying logarithmic model of thin layer drying. This value performed by 4 mm of slice thickness of black potato with 80 °C of drying temperature during 195 min of drying time. This result indicated that the logarithmic model is the most suitable model for interpreting the thin layer drying kinetic of black potato.

5. Nomenclature

MR	moisture content (-)
t	drying time (min, for MR and s, for D)
M	mass (gr)
k	empirical coefficient of drying rate (-)
a	empirical coefficient of constants (-)
g	empirical coefficient of drying rate (-)
b	empirical coefficient of constants (-)
h	empirical coefficient of drying rate (-)
c	empirical coefficient of constants (-)
D	diffusivity (m2/s)
Ht	thickness of the chip (m)
Ea	activation energy (J/mol)
R	gas constant (8.3145 J/mol K)
0 (subscript)	initial
1 (subscript)	continuation
e (subscript)	equilibrium

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