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Short Article

Effect of temperature on sucrose penetration and browning reactions in longan aril during osmotic dehydration

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Abstract: Sucrose penetration and browning reactions in longan aril during osmotic dehydration at various temperatures were examined by measurement of total soluble solid and colour parameter (b*) of longan aril. Mathematical modelling and Arrhenius equation were used to express the changes during the process and the effect of temperature respectively. Parabola models ($Y = a_0 + a_1X + a_2X^2$) were fitted to the set of total soluble solid data where a_0 is the initial total soluble solid and X is the soaking time, because the rate of increase in total soluble solid of longan aril during osmotic dehydration was high in the initial period and gradually decreased until the system reached equilibrium. Linear models ($Y = a_0 + a_1X$) were fitted to the set of b* values where a_0 is the initial value and X is the soaking time. Mathematical equations were created for predicting response values at any temperature ranging from 30 to 90 °C, but the predicted values were slightly lower than the experimental ones.

Keywords: longan, sucrose penetration, browning reactions, osmotic dehydration, mathematical modelling, Arrhenius equation

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Introduction

Longan (*Dimocarpus longan* (Lour.) Steud), commonly called Dragon's-eye in English and Lamyai in Thai, is reported to have originated in north-eastern India, Burma or south China in Yunan province [1]. In Thailand, it is generally grown in Chiang Mai and Lamphun provinces. Many cultivars including Daw, See Chompoo, Haew, Biew Kiew, Dang Klom and Bai Dam are grown [1-3], but Daw is the major cultivar which is grown for food processing supply. Approximately 30% of all produce is used for fresh consumption in the whole country, 20% for export, 40% for dried longan production, and 10% for longan canning process [4]. Longan fruits are brownish, globose to ovoid, and 1.5-2.5 cm in diameter. The skin is thin without protuberances. The aril is white, translucent and sweet with a mild aromatic spiciness [1]. The nutritional composition of a 100 g edible portion of longan consists of 71 calories, 81.0 g moisture, 15.6 g carbohydrate, 1.0 g protein, 1.4 g fat, 0.3 g crude fibre, 0.03 mg vitamin B1, 0.14 mg vitamin B2, 0.3 mg niacin, 56 mg vitamin C, 23 mg calcium, 36 mg phosphorus and 0.4 mg iron [5].

Due to the surplus of longan produce, a number of processes for preserving longan have been developed [6-7]. Osmotic dehydration by soaking the fruit flesh in a concentrated sugar solution is a common process used for fruit preservation. Mass transfer during osmotic dehydration can be divided into two periods, viz. an initial period with a high rate of water removal and solute penetration, followed by a period with a decreasing rate of water removal and solute penetration [8]. The temperature of the process can affect the rate of mass transfer [8] and such reactions as browning reactions [9-10]. To understand the effect of temperature on mass transfer and browning reactions during osmotic dehydration, the knowledge of thermodynamics and kinetics is required. Thermodynamics explains the driving force, the energy and entropy changes and the direction of reaction, while kinetics expresses the speed at which a reaction proceeds. Basically, mathematical models are used to determine the change and speed of reaction, while Arrhenius equation is used to show how the reaction speed is affected by temperature as well as to derive the activation energy of reactions [11].

This work aims to express the effect of temperature on sucrose penetration and browning reactions during osmotic dehydration of longan aril by using mathematical modelling and Arrhenius equation to explain the changes of total soluble solid and b* colour parameter of samples.

Materials and Methods

Osmotic dehydration

Logan aril (Daw) was purchased from a local fruit canning company. It was blanched in boiling water for 1 min before soaking in 70°Brix sucrose solution (longan aril:sucrose solution = 1:1) at room temperature (30$\pm$5 °C) for 24 hours. The whole process was repeated at 50, 60, 70, 80 and 90 °C. Total soluble solid (in °Brix) and colour parameter b* of longan aril were recorded before soaking and then every 4 hours. Total soluble solid was measured by a set of portable refractometers (Models FG 103/113, FG 104/114 and FG 106/116: Beijing Zhongjin Tech Metallurgical Equipment Corp., China), and colour parameter b* was measured by a JUKI Tri-stimulus colorimetre, Model JC801 (Colour Techno System Corp., Japan).

Data analysis and modelling

The experiment at each temperature was done in triplicate. Means of total soluble solid and b^* values were obtained from seven measurements. Mathematical models were applied to describe the changes of recorded data at each temperature and the speed of changes was calculated. The constant (pre-exponential factor or frequency factor) and the activation energy (E_a) of each change in the Arrhenius equation were determined and used to create mathematical models for predicting values of total soluble solid and b* at any temperature ranging from 30 to 90 °C. The linear regression between predicted and experimental values was done to compare their values.

Results and Discussion

Sucrose penetration

The increase in total soluble solid in longan aril expresses the penetration of sucrose from the concentrated sucrose solution. The gain in total soluble solid of longan aril, the initial value before immersion in the sugar solution being at 17.4±0.5°Brix, is shown in Figure 1. Parabola models, $Y = a_0 + a_1X + a_2X^2$, where a_0 is initial total soluble solid of longan aril, a_1 is initial rate of increase, a_2 is acceleration and X is soaking time, can fit this phenomena. The rate of increase in total soluble solid could be estimated from the first-order differential equation of the parabola model [11]: $dY/dX = dY/dt = a_1 + 2a_2X$. The rates of increase in total soluble solid were high at the initial period and gradually decreased until they became the small plus or minus values (Table 1) when the water activity of both the sucrose solution and the product reached equilibrium [8].

From the Arrhenius equation: $k = Ae^{-Ea/RT}$, the constant (A) and the activation energy (E_a) can be determined by taking the natural logarithms of both sides of the above equation to yield a linear equation: $\ln k = \ln A + (-E_a/R)(1/T)$, where ln A is the Y-axis intercept and ($-E_a/R$) is the slope. In this experiment, five linear equations could be created for soaking time at 0, 4, 8, 12 and 16 hours (Figure 2). The equation for soaking time at 20 and 24 hours could not be created because the value of ln k where k was a minus value could not be determined. However, only 2 linear equations at 0 and 4 hours were needed to create the parabola equations for predicting values at any temperature in the experimental range since the value of a_1 and a_2 could be obtained from those two equations (Tables 2-3). The linear regression between the predicted and experimental values could be created and it was found that the predicted values were slightly lower (0.9 time) than the experimental ones (Figure 3).

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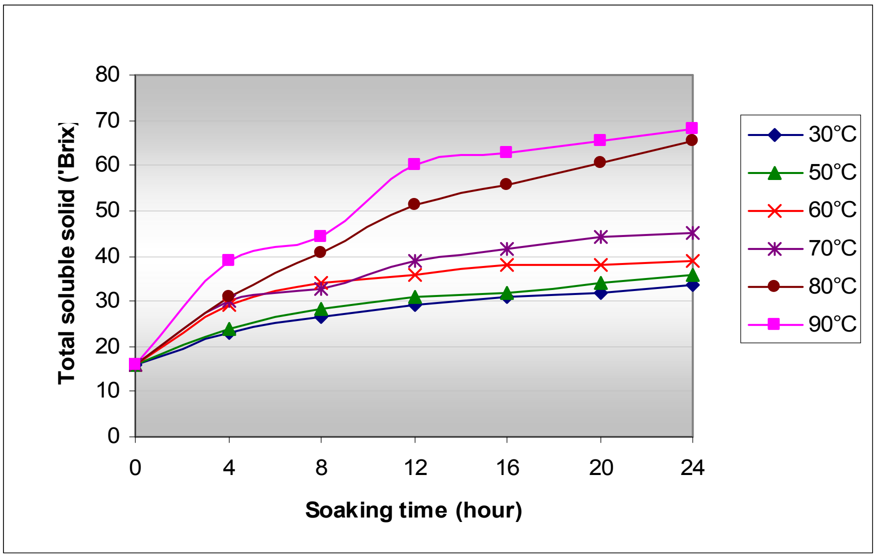

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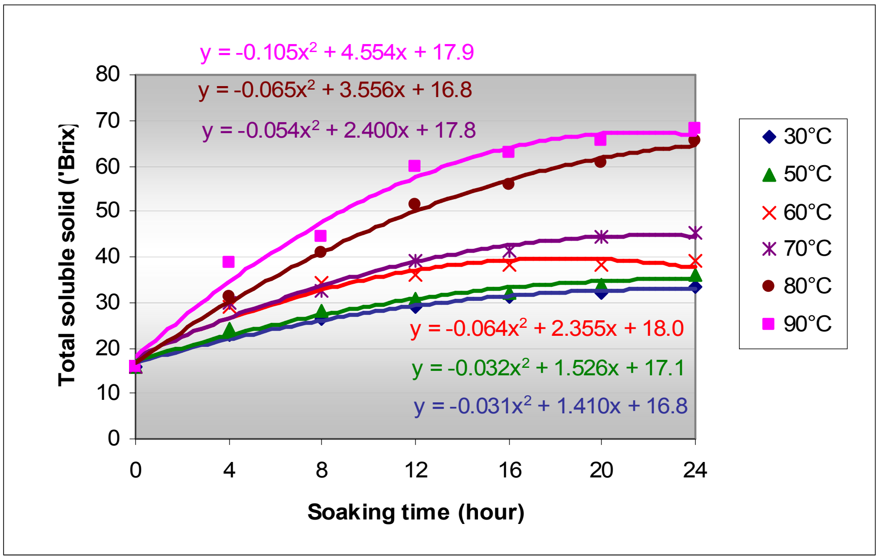

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Figure 1. Changes of total soluble solid in longan aril during osmotic dehydration: (a) raw data, (b) mathematical fit

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Table 1. Change in rate of increase (°Brix /hour) in total soluble solid of longan aril during osmotic dehydration

Temperature	Soaking time (hour)						
(°C)	0	4	8	12	16	20	24
30	1.410	1.162	0.914	0.666	0.418	0.170	-0.078
50	1.526	1.270	1.014	0.758	0.502	0.246	-0.010
60	2.266	1.754	1.242	0.730	0.218	-0.294	-0.806
70	2.330	1.898	1.466	1.034	0.602	0.170	-0.262
80	3.556	3.036	2.516	1.996	1.476	0.956	0.436
90	4.554	3.714	2.874	2.034	1.194	0.354	-0.486

Note: Values are calculated by first-order differential equation: $dY/dX = a_1 + 2a_2X$, where X is soaking time.

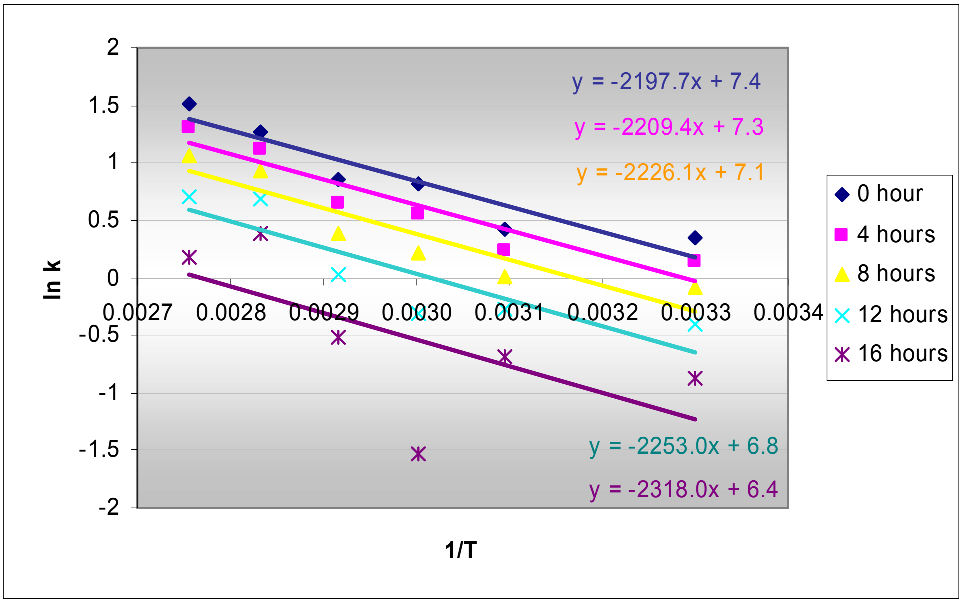

Figure 2. Linear Arrhenius equations from total soluble solid data of longan aril during osmotic dehydration

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Table 2. Parameters for creating the parabola equation for prediction of total soluble solid in longan aril at any temperature (30-90 °C) during osmotic dehydration

Soaking time (hour)	Y-axis intercept, ln A	Slope, $-E_a/R$	A	E_a ($kJ\ mol^{-1}$)	a_1, $Ae^{-Ea/RT}$	a_2, $(Ae^{-Ea/RT} - a_1)/2X_1$
0	7.4	-2197.7	1636.0	18.3	$1636.0e^{-2197.7/T}$	
4	7.3	-2209.4	1480.3	18.4		$(1480.3e^{-2209.4/T} - a_1)/2X_1$

Note: T is temperature in Kelvin.
X_1 is the first recorded time after process was started and it was equal to 4 in this experiment.
Parabola equation used: $Y = a_0 + a_1X + a_2X^2$, where a_0 is the initial total soluble solid of longan aril.

Table 3. Mathematical models for predicting soluble solid in longan aril during osmotic dehydration at temperature ranging from 30 to 90 °C

Temperature (°C)	Model
30	$Y = -0.04X^2 + 1.40X + a_0$
40	$Y = -0.05X^2 + 1.35X + a_0$
50	$Y = -0.06X^2 + 2.16X + a_0$
60	$Y = -0.08X^2 + 2.64X + a_0$
70	$Y = -0.09X^2 + 3.18X + a_0$
80	$Y = -0.11X^2 + 3.80X + a_0$
90	$Y = -0.13X^2 + 4.49X + a_0$

Note: X is soaking time; a_0 is the initial total soluble solid of longan aril.

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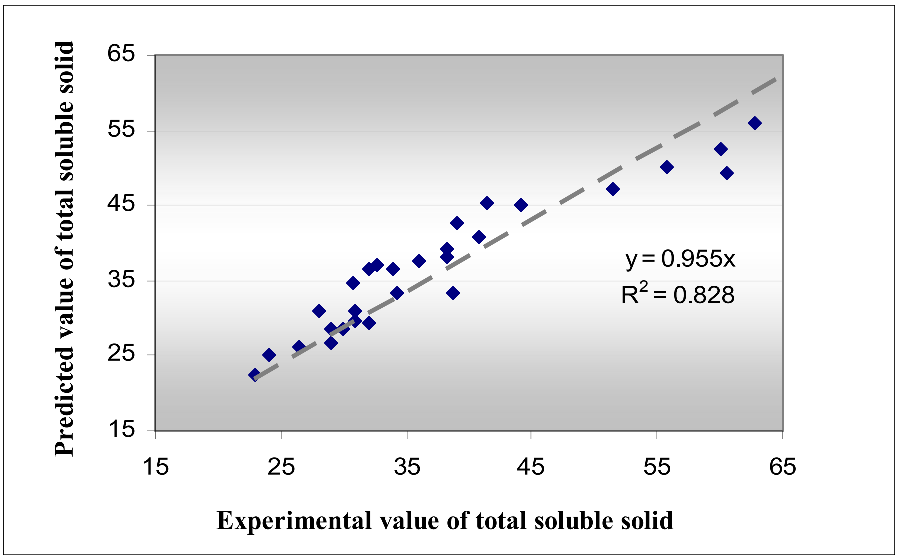

Figure 3. Linear regression between predicted and experimental values of total soluble solid

Browning reactions

Browning reactions in this study were nonenzymatic browning reactions which might be Maillard reaction and ascorbic acid browning since reducing sugar, protein and ascorbic acid were found in longan aril [5]. Maillard reaction is that between carbonyl groups (from reducing sugars, aldehydes, ketones, lipid oxidation products) and amino compounds (lysine, glycine, peptides, amines, ammonia, proteins) [12], while ascorbic acid browning is the thermal decomposition of ascorbic acid [13].

The colour parameter, b*, is one of the international standards for colour measurement adopted by the Commission Internationale d' Eclairage (CIE) in 1976. Parameter b* is a chromatic component which ranges from -120 (blue) to 120 (yellow) [14], and it has been used to express the brownness of fruit wines [15]. In this study the parameter b* was used to measure the browning reactions occurring during osmotic dehydration. The initial value of b* was 3.4 $\pm$ 0.3, which was increased when high temperatures (over 50 °C) were used (Figure 4), since nonenzymatic browning reactions are time and temperature dependent and are obviously faster at a higher temperature [9]. Linear models, $Y = a_0 + a_1X$, were fitted to this data set where a_0 is the initial value of b*, a_1 is its rate of increase and X is soaking time. The constant (A) and the activation energy (E_a) could be determined from a linear Arrhenius equation (Figure 5 and Table 4), and linear equations for predicting the value of b* during the process at any temperature ranging from 30 to 70 °C were created (Table 5). The predicted values were regressed against experimental values whereupon it was found that the predicted values were slightly smaller (0.9 time) than the experimental ones (Figure 6).

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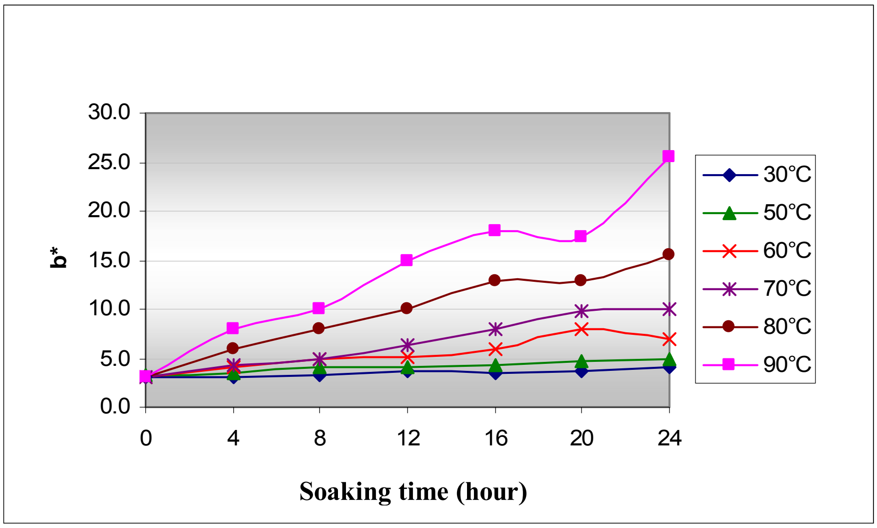

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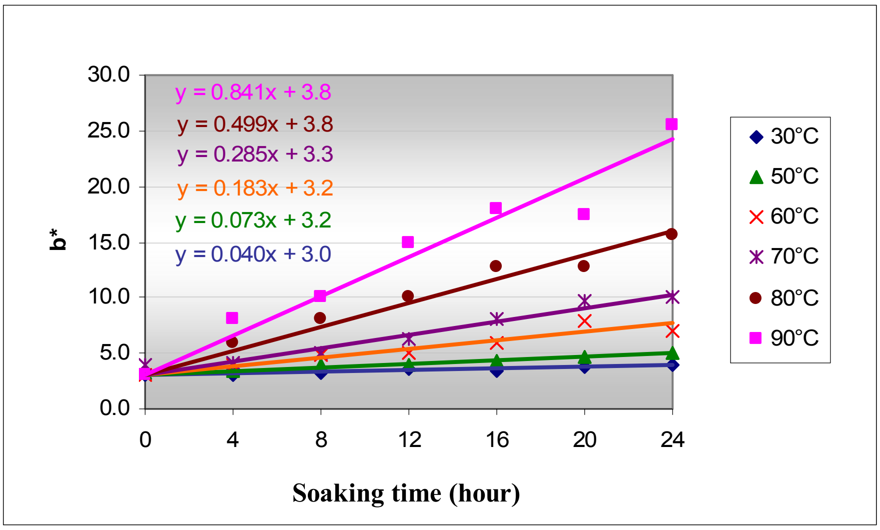

(b)

Figure 4. Changes of parameter b* of longan aril during osmotic dehydration: (a) raw data, (b) mathematical fit

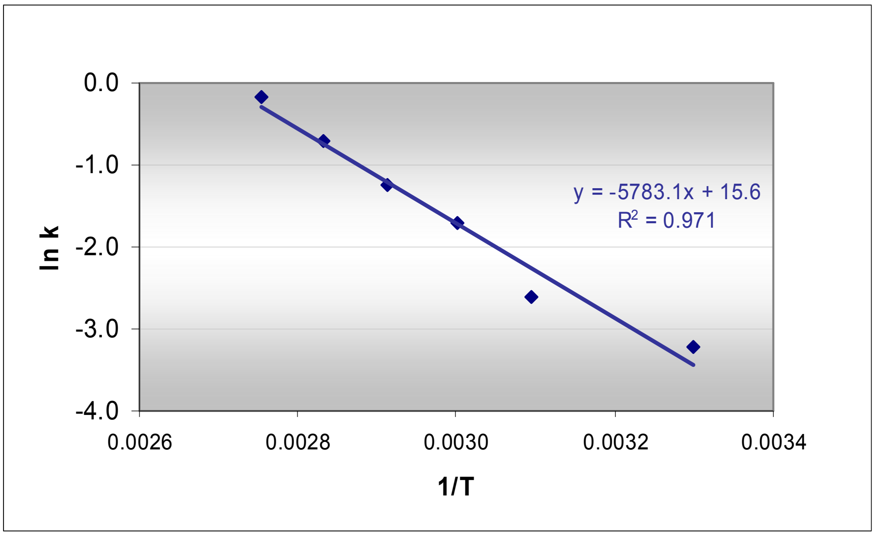

Figure 5. A linear Arrhenius equation from b* values of longan aril during osmotic dehydration

Table 4. Parameters for creating the linear equation to predict values of b* of longan aril at 30-90 °C during osmotic dehydration

Y-axis intercept, ln A	Slope, $-E_a/R$	A	E_a ($kJ\ mol^{-1}$)	a_1, $Ae^{-Ea/RT}$
15.6	-5783.1	5,956,538.0	48.1	$5,956,538.0e^{-5783.1/T}$

Note: T is temperature in Kelvin.
Linear models used: $Y = a_0 + a_1X$, where a_0 is the initial value of b*

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Table 5. Mathematical models for predicting parameter b* of longan aril during osmotic dehydration at 30-90 °C

Temperature (°C)	Model
30	$Y = 0.03X + a_0$
40	$Y = 0.06X + a_0$
50	$Y = 0.10X + a_0$
60	$Y = 0.17X + a_0$
70	$Y = 0.29X + a_0$
80	$Y = 0.46X + a_0$
90	$Y = 0.72X + a_0$

Note: X is soaking time; a_0 is initial value of b*.

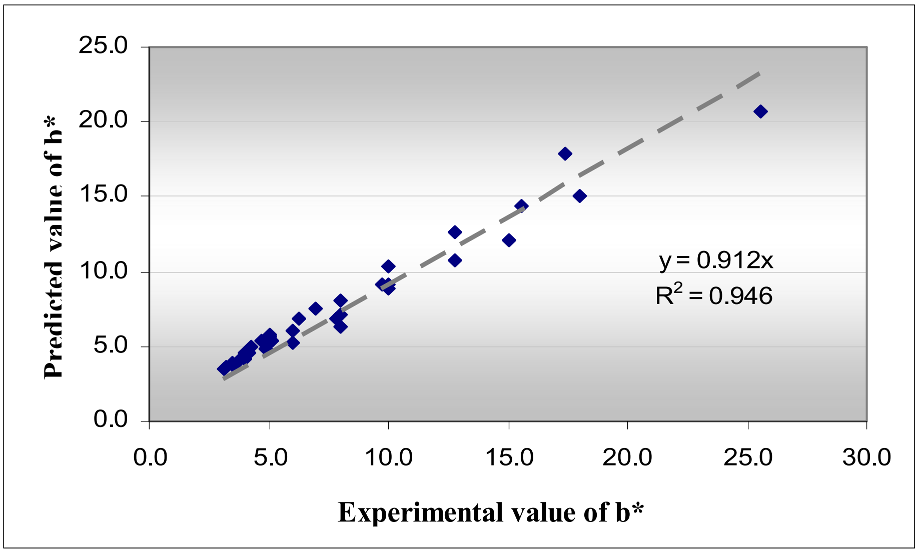

Figure 6. Linear regression between predicted and experimental values of b*

Conclusions

This study has shown how to express the effect of temperature on two phenomena, i.e. sucrose penetration and browning reactions, during osmotic dehydration of longan aril by using mathematical modelling and Arrhenius equation. The results allow researchers to predict response values during the process at any temperature in the experimental range, which could be useful for a process control when

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the final total soluble solid of longan aril is set or the initial total soluble solid of longan aril is changed, or when it is necessary to change the temperature of process. However, the result of this work is applicable only when a 70 °Brix sucrose solution is used. More experimentation is needed for other sucrose concentrations.

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