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Kinetics of Dimensional Changes in Glutinous Rice at Different Rice-Water Ratio and Soaking Time

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Abstract

White glutinous or sticky rice must be soaked in water before cooking to gelatinize its starch. There has been limited work into the dimensional changes of soaked glutinous rice, owing to differences in rice-to-water ratios and soaking times. The objective of this work is to investigate the kinetics of these dimensions' changes during a range of ratios and soaking times. Cultivar Siding glutinous rice was used for this work. The work varied the glutinous rice-water ratios A, B, and C and soaking times to determine changes in length, width, thickness, equivalent diameter, surface area, and projected area of glutinous rice. The results showed that the soaked glutinous rice in condition C had the highest increment in dimensional changes compared to conditions A and B. The kinetics of dimensional changes in glutinous rice during soaking at room temperature were also investigated. The Page model accurately predicted the dimensions changes of soaked glutinous rice in condition C, with the highest R^2 value of length (0.9527), width (0.9881), thickness (0.9945), equivalent diameter (0.9761), and projected area (0.9603) compared to other conditions. This suggests that the Page model is useful for predicting the dimensions of soaked glutinous rice at any time.

Keywords: Dimensional expansion; Equivalent diameter change; Page model; Projected area; Whole grain

1. Introduction

Rice is a crucial food crop for most people worldwide, serving as the primary food source for more than half of the population. In Asia, rice contributes to approximately 90% of global production and consumption [1]. Regarding energy, protein, fiber, and nutrients for health, rice is a good food source. Glutinous rice (*Oryza sativa* var. glutinosa) is among the most popular worldwide. It has opaque grain and low amylose content in the starch [2]. Glutinous rice needs to be soaked in water before cooking[3]. Soaking is a hydrothermal process in the glutinous rice process and a crucial step in cooking. When water diffuses into the glutinous rice, it becomes swell and gelatinizes. Also, the water diffusion makes it soft. The dimensions and volume increase as water is absorbed until saturation occurs [4].

Mathematical modeling is an approach authors use to estimate the possible results of any operation by analyzing a model that closely imitates the actual situation and applying mathematical equations. The physical properties, including dimensions of rice samples, were studied to determine characteristics desirable for potential food applications[5]. Based on the previous studies, some of the models used in the food application such as Modified Gompertz [6], Pseudo-first- and second-order [7]–[9], and Intra-particle diffusion model [10]. However, the Page model is one of the most successful and well-fitted models of rice soaking at certain temperatures from 25 to 70 °C [11]. According to Thakur & Gupta [12], Kashaninejad et al. [13], and Cheevitsopon & Noomhorm [14], these previous studies concluded that the Page model generates the best fit with higher R^2 values than other selected models (Exponential, Henderson & Pabis, Lewis, Modified Page and Two-term models) and gave better predictions than other models, and satisfactorily described soaking properties of rice. The model constant could also be used to predict the moisture content at the equilibrium state of the kernels [15]. Water diffusion into the kernel during soaking influenced the size increase. Thus, changes in kernel size are essential for ensuring cooking quality.

However, limited work has been reported on dimensional changes of glutinous rice during soaking. Also, the predictions of the dimensional changes of soaked glutinous rice (cultivar Siding) using the Page model are limited. However, Dongbang & Nuantong, and Jimoh et al. studied glutinous rice's dehydration or drying kinetics using a page model [16], [17]. Therefore, this work offers a novel perspective on (1) investigation of the effects of glutinous rice-water ratio and soaking time on the dimensions of glutinous and (2) analysis of the effects of dimensional changes of soaked glutinous rice on the kinetic constant of the Page model.

2. Methodology

2.1. Sample preparation

White glutinous rice (*Oryza sativa* var. glutinosa) grains were obtained from a cultivar of Siding. The glutinous rice grains were transferred at room temperature to the laboratory directly from a farm located in Kuala Selangor, Selangor, Malaysia. They were stored overnight at 4 °C before analysis.

2.2. Soaking test of glutinous rice

Fifty grams of glutinous rice were mixed with tap water in plastic containers under different conditions. The soaking test was modified by following the procedures of Li et al. [18] and Hanucharoenkul et al. [2]. For the soaking test, glutinous rice was soaked in water at three conditions, A, B, and C, of 1:1.1, 1:1.3, and 1:1.5 ratios (glutinous rice: water, g: g) respectively at different times (i.e., 5, 10, 15, 20, 25, 30, 60, 90, 120, 150, and 180 min) at room temperature (24°C). Then, the glutinous rice was taken and separated from the water after soaking each time. One hundred glutinous rice grains were chosen randomly to determine the dimensions.

2.3. Determination of physical properties

Length (L), width (W), and thickness (T) of one hundred glutinous rice grains, as shown in Fig. 1, were measured by using a digital vernier caliper (Series 500, Mitutoyo, Japan) with 0.01 mm sensitivity to determine the mean size of the samples [19].

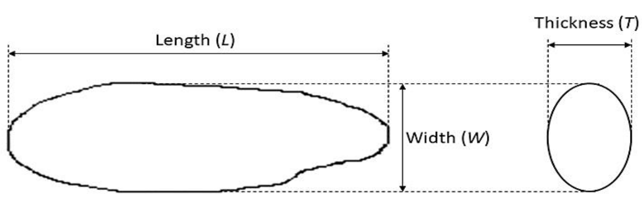


Figure 1. Dimensions of glutinous rice

Using the measured length, width, and thickness, the equivalent diameter (De) of glutinous rice was determined [20] as equation (1):

$$De = \left(\frac{L(W+T)^2}{4}\right)^{\frac{1}{3}} \quad (1)$$

The surface area (SA) was determined by using the following equations (2) and (3) [20], respectively:

$$\boldsymbol{SA} = \frac{\boldsymbol{\pi} \times \boldsymbol{B} \times \boldsymbol{L}^2}{\mathbf{2} \times \boldsymbol{L} - \boldsymbol{B}} \quad (2)$$

Where $\boldsymbol{B} = (\boldsymbol{W} \times \boldsymbol{T})^{\mathbf{1/2}}$ (3)

The projected area of glutinous rice (PA_L) in a perpendicular direction to length was calculated by using equation (4) [14] as below:

$$PA_L = \left(\frac{\pi WL}{4}\right) \quad (4)$$

2.4. Mathematical model of dimensional changes

Equation (5) shows that the constant and coefficient of the Page model [14] were estimated using nonlinear regression.

$$Dt = exp(-kt^n) \quad (5)$$

Where Dt is dimension parameters (unit depends on the measured parameters), t is the time of soaking (min), $and\ k$ and n are constants of the model (no unit).

Three variables were analyzed to assess the goodness of fit of the Page model: the coefficient of determination (R^2), standard error of estimate (SEE), and root mean square error ($RMSE$). The R^2, SEE, and $RMSE$ can be calculated [14], [21] using equations (6), (7), and (8):

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(Dt_{exp,i} - Dt_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(Dt_{exp,i} - \overline{Dt}\right)^2} \quad (6)$$

$$SEE = \left[\frac{\sum_{i=1}^{N}\left(Dt_{exp,i} - Dt_{pre,i}\right)^2}{N-n}\right]^{\frac{1}{2}} \quad (7)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(Dt_{exp,i} - Dt_{pre,i}\right)^2\right]^{\frac{1}{2}} \quad (8)$$

where $Dt_{exp,i}$ = the experimental dimensions at a particular time, $Dt_{pre,i}$ = the prediction dimensions at a specific time, and $\overline{Dt}$ = the mean value of dimensions. The predicted dimensional changes were compared to the experimental dimensional changes. According to Hayaloglu et al.[22], , the R^2 values near one would be a better fit. Meanwhile, lower SEE and $RMSE$ values indicated the prediction was closer to the experimental data.

2.5. Statistical analysis

Tukey's test was performed using Minitab Statistic 18 Edition to differentiate and determine the significance between the mean values. Five replications were carried out for each analysis. The mean and standard deviation were determined at a 95% confidence limit (p<0.05). The measured dimensions at each soaking time were used to perform the kinetic Page model (equation as shown in equation 5) using the Excel Solver Software. After performing the Page model, the R^2, SEE $RMSE$, k, and n values were determined.

3. Results and discussions

3.1. Dimensions of glutinous rice

Dimension is one of the essential factors that affect the quality of glutinous rice during soaking. Table 1 shows the dimensions of glutinous rice, such as length, width, thickness equivalent diameter, surface area, and projected area during soaking in different glutinous rice-water ratios (conditions A, B, and C). The initial length of glutinous rice in conditions A, B, and C was 6.24 ±0.07 mm. As shown in Table 1, the length of soaked glutinous rice in condition A was increased gradually with the value of 6.43 ±0.09 mm at 5 min. It continued to grow until it reached 7.46 ±0.08 mm (180 min) with an increment of 19.55%. Next, the length of glutinous rice attained at 5 min in condition B during soaking was 6.48 ±0.04 mm. After 180 min of soaking, it increased gradually by 26.44% with a value of 7.89 ±0.06 mm. The length of soaked glutinous rice in condition C was 6.67 ±0.08 mm at 5 min. After that, it reached 7.99 ±0.10 mm at 180 min of soaking with an increment of 28.04%.

Based on Table 1, the time significantly affected the width of soaked glutinous rice at $p<0.05$. In conditions A, B, and C, the initial width value was 1.70 ±0.08 mm. The width of glutinous rice attained during soaking at 5 min in condition A was 1.78 ±0.04 mm. After 180 min of soaking, it increased gradually by 19.41% with a value of 2.03 ±0.07 mm. Next, the width of soaked glutinous rice in condition B was increased from 1.78 ±0.09 mm (5 min) to 2.05 ±0.05 mm (180 min). It has an increment of 20.59%. The soaked glutinous rice in condition C had increased with the value of 1.79 ±0.07 mm at 5 min. Then, it reached 2.09 ±0.06 mm at 180 min with an increment of 22.94%.

The initial thickness value was 1.41 ±0.06 mm. The thickness of soaked glutinous rice attained at 5 min in condition A was 1.50 ±0.08 mm. At 180 min of soaking, it increased gradually to 21.28%, with a value of 1.71 ±0.07 mm.

Table 1. Mean values of length, width, and thickness of glutinous rice during soaking at different conditions and time

Time (min)	*L* (mm)			*W* (mm)			*T* (mm)		
	A	B	C	A	B	C	A	B	C
0	6.24 ±0.07^{h}	6.24 ±0.07^{j}	6.24 ±0.07^{h}	1.70 ±0.08^{f}	1.70 ±0.08^{g}	1.70 ±0.08^{f}	1.41 ±0.06^{d}	1.41 ±0.06^{g}	1.41 ±0.06^{f}
5	6.43 ±0.09^{g}	6.48 ±0.04^{i}	6.67 ±0.08^{g}	1.78 ±0.04^{ef}	1.78 ±0.09^{fg}	1.79 ±0.07^{ef}	1.50 ±0.08^{cd}	1.52 ±0.06^{f}	1.55 ±0.07^{e}
10	6.70 ±0.08^{f}	6.87 ±0.08^{h}	6.98 ±0.08^{f}	1.79 ±0.10^{ef}	1.81 ±0.07^{ef}	1.85 ±0.09^{de}	1.52 ±0.09^{bcd}	1.55 ±0.07^{ef}	1.59 ±0.09^{e}
15	6.82 ±0.08^{f}	6.95 ±0.09^{gh}	7.07 ±0.07^{ef}	1.79 ±0.06^{ef}	1.82 ±0.06^{ef}	1.87 ±0.08^{cde}	1.56 ±0.14^{bc}	1.57 ±0.08^{ef}	1.61 ±0.07^{de}
20	7.00 ±0.08^{e}	7.03 ±0.09^{fg}	7.11 ±0.07^{e}	1.81 ±0.07^{de}	1.86 ±0.07^{def}	1.89 ±0.07^{cde}	1.57 ±0.08^{bc}	1.60 ±0.07^{def}	1.64 ±0.05^{cde}
25	7.04 ±0.08^{de}	7.09 ±0.08^{ef}	7.12 ±0.06^{e}	1.86 ±0.08c^{de}	1.87 ±0.08^{def}	1.90 ±0.07^{cde}	1.58 ±0.06^{bc}	1.62 ±0.04^{cde}	1.65 ±0.05^{bcde}
30	7.09 ±0.07^{de}	7.11 ±0.07^{ef}	7.14 ±0.07^{de}	1.91 ±0.07^{bcd}	1.90 ±0.08^{cde}	1.90 ±0.08^{cde}	1.59 ±0.07^{abc}	1.62 ±0.06^{cde}	1.65 ±0.07^{bcde}
60	7.15 ±0.09^{cd}	7.19 ±0.07^{de}	7.25 ±0.09^{cd}	1.93 ±0.09^{abc}	1.94 ±0.05^{bcd}	1.95 ±0.07^{bcd}	1.60 ±0.07^{abc}	1.64 ±0.06^{bcde}	1.66 ±0.07^{abcde}
90	7.27 ±0.09^{bc}	7.30 ±0.08^{d}	7.37 ±0.11^{c}	1.95 ±0.09^{abc}	1.96 ±0.07^{abcd}	1.98 ±0.08^{abc}	1.62 ±0.06^{abc}	1.67 ±0.07^{abcd}	1.71 ±0.09^{abcd}
120	7.33 ±0.09^{b}	7.55 ±0.09^{c}	7.59 ±0.09^{b}	2.00 ±0.05^{ab}	2.00 ±0.07^{abc}	2.02 ±0.08^{ab}	1.63 ±0.09^{ab}	1.71 ±0.06^{abc}	1.73 ±0.08^{abc}
150	7.39 ±0.09^{ab}	7.73 ±0.09^{b}	7.66 ±0.07^{b}	2.03 ±0.05^{a}	2.04 ±0.05^{ab}	2.09 ±0.06^{a}	1.71 ±0.07^{a}	1.73 ±0.05^{ab}	1.76 ±0.08^{ab}
180	7.46 ±0.08^{a}	7.89 ±0.06^{a}	7.99 ±0.10^{a}	2.03 ±0.07^{a}	2.05 ±0.05^{a}	2.09 ±0.06^{a}	1.71 ±0.07^{a}	1.74 ±0.07^{a}	1.77 ±0.08^{a}

Data are expressed mean ±SD; *L*, length (mm); *W*, width (mm); *T*, thickness (mm); A, soaking condition using glutinous rice-water ratio 1:1.1; B, soaking condition using glutinous rice-water ratio 1:1.3; C, soaking condition using glutinous rice-water ratio 1:1.5. Different letters indicate statistically significant differences exist $p<0.05$ for each column. Means do not share a letter are significantly different. Tukey's test was applied with 95% simultaneous confidence intervals.

Table 2 shows the change in equivalent diameter during soaking in different conditions. The initial equivalent diameter of glutinous rice was 2.47 ±0.08 mm. Table 2 showed that the equivalent diameter of glutinous rice in condition A was 2.59 ±0.11 mm at 5 min of soaking. Then, it increased gradually until it reached 2.97 ±0.08 mm at 180 min with an increment of 20.24%.

The initial surface area of glutinous rice in conditions A, B, and C was 43.21 ±1.94 mm^2. As shown in Table 2, the surface area of soaked glutinous rice in condition A was increased gradually with the value of 46.56 ±2.58 mm^2 at 5 min. It continued to grow until it reached 61.70 ±2.20 mm^2 (180 min) with an increment of 42.79%. Next, the surface area of glutinous rice attained at 5 min in condition B during soaking was 46.85 ±1.85 mm^2. After 180 min of soaking, it increased gradually by 54.83% with a value of 66.90 ±1.60 mm^2. The surface area of soaked glutinous rice in condition C was 48.87 ±2.10 mm^2 at 5 min. After that, it reached 68.92 ±0.01 mm^2 at 180 min of soaking with an increment of 59.50%. The surface area of grain is important in designing conveying equipment and cleaning and separating equipment [23].

Based on Table 2, the time affected the projected area of soaked glutinous rice in conditions A, B, and C, and the initial value was 8.34 ±0.48. The projected area of glutinous rice attained during soaking at 5 min in condition A was 9.05 ±0.62. After 180 min of soaking, it increased gradually by 42.69% to 11.90 ±0.51.

Next, the projected area of soaked glutinous rice in condition B was increased from 9.06 ± 0.51 (5 min) to 12.71 ± 0.39 (180 min). It has an increment of 52.28%. The soaked glutinous rice in condition C had increased with the value of 9.38 ±0.49 at 5 min. Then, it reached 13.12 ±0.50 at 180 min with an increment of 57.31%. The projected area of soaked grain is essential in designing grain handling and transportation machines because it influences the flow rate and pressure drop. Furthermore, it is important in designing grain storage systems because it affects storage capacity and grain stability.

Table 2. Mean values of equivalent diameter, surface area, and projected area of glutinous rice during soaking at different conditions and time

Time (min)	***De*** **(mm)**			***SA*** (mm^2)			PA_L		
	A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
0	2.47 ±0.08^{h}	2.47 ±0.08^{h}	2.47 ±0.08^{h}	43.21 ±1.94^{i}	43.21 ±1.94^{i}	43.21 ±1.94^{h}	8.34 ±0.48^{j}	8.34 ±0.48^{i}	8.34 ±0.48^{h}
5	2.59 ±0.11^{gh}	2.60 ±0.08^{g}	2.65 ±0.08^{g}	46.56 ±2.58^{h}	46.85 ±1.95^{h}	48.87 ±2.10^{g}	9.05 ±0.62^{ij}	9.06 ±0.51^{hi}	9.38 ±0.49^{g}
10	2.63 ±0.08^{fg}	2.69 ±0.08^{fg}	2.74 ±0.10^{fg}	48.97 ±1.42^{gh}	51.20 ±2.11^{g}	53.07 ±2.35^{f}	9.37 ±0.31^{hi}	9.77 ±0.50^{gh}	10.15 ±0.57^{fg}
15	2.67 ±0.10^{efg}	2.71 ±0.08^{efg}	2.78 ±0.09^{ef}	50.33 ±1.74^{fg}	52.19 ±1.97^{fg}	54.37 ±2.22^{f}	9.59 ±0.40^{ghi}	9.94 ±0.45^{fg}	10.39 ±0.54^{ef}
20	2.71 ±0.09^{defg}	2.76 ±0.08^{def}	2.81 ±0.07^{def}	52.49 ±2.11^{ef}	53.77 ±2.26^{efg}	55.17 ±2.13^{ef}	9.95 ±0.50^{fgh}	10.27 ±0.51^{efg}	10.56 ±0.51^{ef}
25	2.75 ±0.08^{cdef}	2.78 ±0.07^{cdef}	2.82 ±0.06^{def}	53.87 ±2.35^{de}	54.57 ±2.30^{def}	55.47 ±1.87^{ef}	10.29 ±0.57^{efg}	10.42 ±0.56^{efg}	10.63 ±0.45^{ef}
30	2.79 ±0.08^{bcde}	2.80 ±0.08^{cde}	2.82 ±0.08^{def}	55.36 ±2.12^{cde}	55.37 ±2.33^{de}	55.68 ±2.22^{ef}	10.64 ±0.51^{def}	10.61 ±0.56^{def}	10.66 ±0.54^{ef}
60	2.81 ±0.09^{bcd}	2.85 ±0.06^{cd}	2.87 ±0.08^{cde}	56.38 ±2.70^{cd}	56.99 ±1.66^{cd}	57.82 ±2.23^{de}	10.84 ±0.65^{cde}	10.96 ±0.38^{de}	11.11 ±0.52^{de}
90	2.85 ±0.09^{abc}	2.89 ±0.08^{bc}	2.93 ±0.10^{bcd}	58.04 ±2.64^{bc}	58.55 ±2.16^{c}	59.71 ±2.65^{cd}	11.14 ±0.62^{bcd}	11.24 ±0.51^{cd}	11.47 ±0.60^{cd}
120	2.89 ±0.08^{ab}	2.96 ±0.07^{ab}	2.99 ±0.09^{abc}	59.68 ±1.85^{ab}	62.07 ±2.20^{b}	62.92 ±2.52^{bc}	11.52 ±0.40^{abc}	11.86 ±0.51^{bc}	12.05 ±0.59^{bc}
150	2.96 ±0.07^{a}	3.02 ±0.06^{a}	3.05 ±0.08^{ab}	60.94 ±1.88^{ab}	64.90 ±2.09^{ab}	65.17 ±1.86^{b}	11.79 ±0.41^{ab}	12.39 ±0.45^{ab}	12.58 ±0.43^{ab}
180	2.97 ±0.08^{a}	3.05 ±0.06^{a}	3.10 ±0.08^{a}	61.70 ±2.20^{a}	66.90 ±1.60^{a}	68.92 ±2.27^{a}	11.90 ±0.51^{a}	12.71 ±0.39^{a}	13.12 ±0.50^{a}

Data are expressed mean ±SD; *De*, equivalent diameter (mm); *SA*, surface area (mm^2); PA_L, projected area; A, soaking condition using glutinous rice-water ratio 1:1.1; B, soaking condition using glutinous rice-water ratio 1:1.3; C, soaking condition using glutinous rice-water ratio 1:1.5. Different letters indicate statistically significant differences exist p<0.05 for each column. Means do not share a letter are significantly different. Tukey's test was applied with 95% simultaneous confidence intervals.

3.2. Analysis of Page modeling kinetic

Table 3 shows the comparison variables of the Page model to fit dimensional changes of glutinous rice during soaking. It can be seen that the Page model presents an excellent fit for changes in thickness. Therefore, the Page model was considered the best model in the present work for describing the dimensional changes of glutinous rice during soaking within the experimental range of work. The Page model has also been suggested by Kashaninejad et al. [13], Muchlisyiyah et al. [24], and Cheevitsopon & Noomhorm [14] for describing the soaking behavior of white and brown rice.

For condition A, the R^2 values for predicting length, width, thickness, equivalent diameter, surface area, and projected area were 0.9701, 0.9630, 0.9332, 0.9787, and 0.9835, respectively. In contrast, the R^2 values for condition B were 0.9408, 0.9828, 0.9790, 0.9746, and 0.9662, while condition C showed the R^2 values of 0.9364, 0.9613, 0.9760, 0.9649, and 0.9508 for length, width, thickness, equivalent diameter, surface area, and projected area, respectively.

Table 3. The analysis results obtained for the Page model, coefficients of determination *(R^2)*, standard estimate error *(SEE)*, and root mean square error *(RMSE)* for soaked glutinous rice in conditions A, B, and C (different glutinous rice-water ratio)

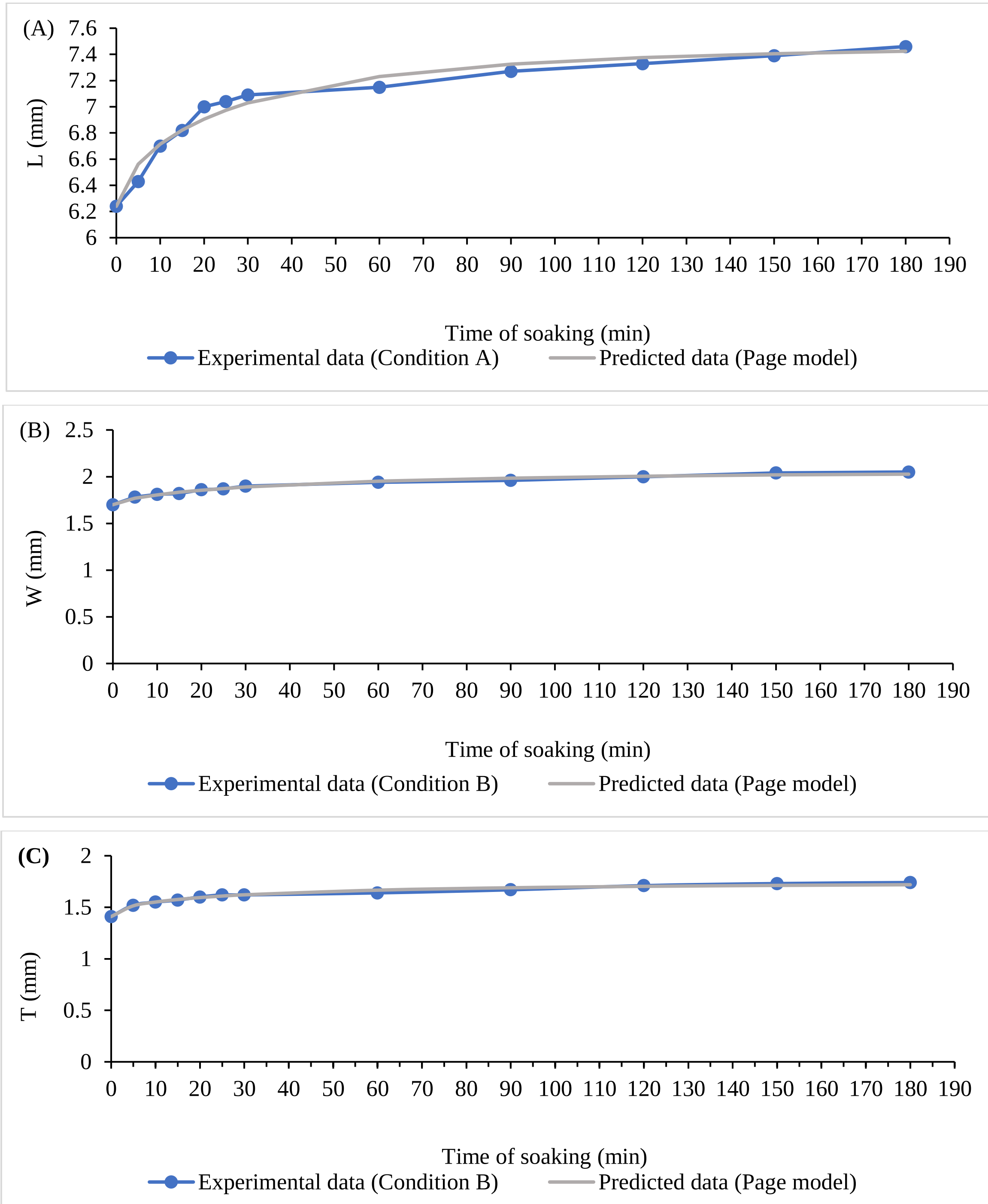
Dimensions	Condition	Model constant		R^2	*SEE*	*RMSE*
Length	A	k = 0.1025;	n = 0.6814	**0.9701**	**0.0692**	**0.0631**
	B	k = 0.1006;	n = 0.5871	0.9408	0.1210	0.1104
	C	k = 0.1490;	n = 0.4854	0.9364	0.1210	0.1104
Width	A	k = 0.0475;	n = 0.8080	0.9630	0.0221	0.0201
	B	k = 0.0717;	n = 0.6999	**0.9828**	**0.0148**	**0.0135**
	C	k = 0.0991;	n = 0.6168	0.9613	0.0238	0.0218
Thickness	A	k = 0.1505;	n = 0.5188	0.9332	0.0228	0.0208
	B	k = 0.1560;	n = 0.5522	**0.9790**	**0.0144**	**0.0132**
	C	k = 0.2240;	n = 0.4789	0.9760	0.0162	0.0148
Equivalent diameter	A	k = 0.0956;	n = 0.6500	**0.9787**	**0.0230**	**0.0210**
	B	k = 0.1057;	n = 0.6064	0.9746	0.0283	0.0258
	C	k = 0.1522;	n = 0.5182	0.9649	0.0340	0.0310
Projected area	A	k = 0.0673;	n = 0.7392	**0.9835**	**0.1533**	**0.1399**
	B	k = 0.0757;	n = 0.6554	0.9662	0.2500	0.2282
	C	k = 0.1064;	n = 0.5666	0.9508	0.3086	0.2818

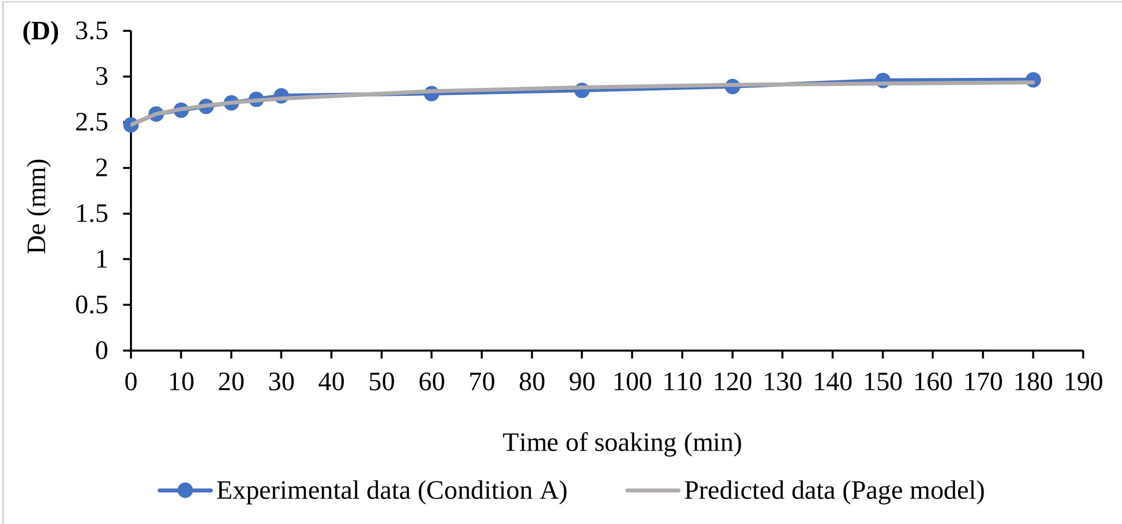
A soaking condition using glutinous rice-water ratio 1:1.1; B, soaking condition using glutinous rice-water ratio 1:1.3; C, soaking condition using glutinous rice-water ratio 1:1.5. k, n, fitting constants; R^2, coefficient of determination; SEE, standard error of estimate; *RMSE*, root mean square error.

Additionally, the relationship between dimensional changes and the Page model can be described by determining the Page constant (k) and coefficient (n) values. For dimensional changes of soaked glutinous rice, the k values were increased from 0.1025 to 0.1490 (for length), 0.0475 to 0.0991 (width), 0.1505 to 0.2240 (thickness), 0.0956 to 0.1522 (equivalent diameter), and 0.0673 to 0.1064 (projected area) in conditions A, B and C, respectively. Meanwhile, the n values obtained ranged from 0.4854 to 0.6814 (length), 0.6168 to 0.8080 (width), 0.4789 to 0.5188 (thickness), 0.5182 to 0.6500 (equivalent diameter), and 0.0.5666 to 0.7392 (projected area) for the dimensional changes of soaked glutinous rice in conditions A, B, and C, respectively. The predictions based on the Page model showed that the *SEE* and *RMSE* values varied between 0.0144 and 0.3086 and 0.0132 and 0.2818, respectively, for describing the dimensional changes of glutinous rice in conditions A, B, and C during soaking.

Thus, the results showed that the length, equivalent diameter, and projected area of soaked glutinous rice in condition A, which had the highest R^2 values, were the most fitted with the prediction of the Page model compared to other conditions. Meanwhile, condition B had the highest R^2 values in width and thickness compared to conditions A and C. The relationship between the effects of soaking on these dimensions and different conditions (glutinous rice-water ratio) was proven by evaluating the constant and coefficient values of the Page model, namely, k and n. These expressions with acceptable R^2, standard error of estimate, and root mean square error are presented in Table 3. It can be used to estimate the dimensional changes of glutinous rice, including length, width, thickness, equivalent diameter, and projected area at any time during the soaking process.

Considering the obtained Page model constants using dimensions, the results showed that the experimental data for conditions A and B had the highest R^2, which indicates the best fit with the Page model when compared to condition C. It can be seen in Fig. 2 (A, B, C, D, and E) that the Page model well fitted the experimental curve of glutinous rice in conditions A and B and the model fit curve.





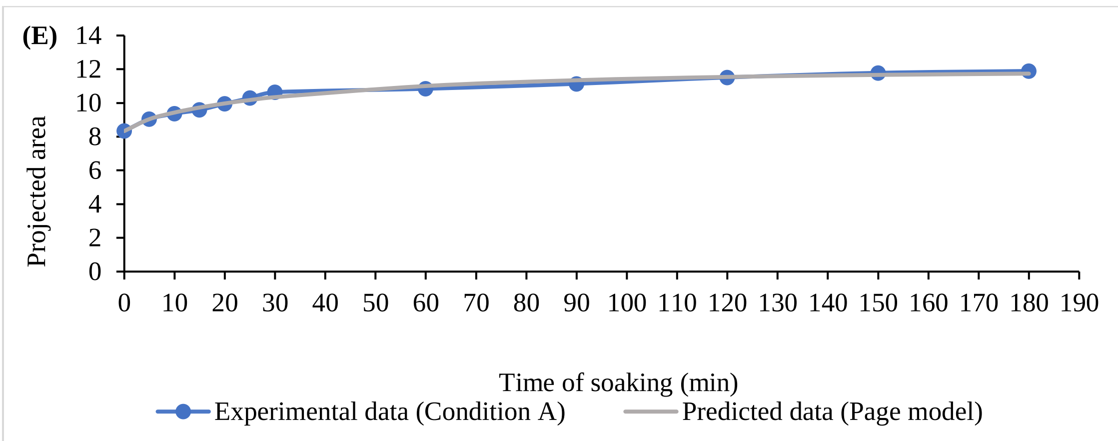


Figure 2. The experiment curve and the most fitted Page model curve of (A) length, (B) width, (C) thickness, (D) equivalent diameter, and (E) projected area of glutinous rice soaked in conditions A and B

4. Conclusions

Soaking is the most essential method in the glutinous rice process. In soaking tests, glutinous rice showed significant (p<0.05) increases in dimensional changes as soaking time and glutinous rice-water ratio were increased. In this work, the highest dimensions values of soaked glutinous rice were achieved at 180 minutes for conditions A, B, and C. During soaking, the glutinous rice in condition C was the most affected by the glutinous rice-water ratio and soaking time, resulting in the highest increment in dimensional changes compared to conditions A and B. Furthermore, this work presents a Page model that describes the changes in length, width, thickness, equivalent diameter, and projected area.

In comparison to conditions B and C, the length, equivalent diameter, and projected area changes of soaked glutinous rice in condition A best fitted the Page model with the highest R^2 in predictions of length (0.9701), equivalent diameter (0.9787) and projected area (0.9835). Meanwhile, condition B had the best-fitted Page model with width (R^2=0.9828) and thickness (R^2=0.9790). The relationship between the dimensions and different conditions (glutinous rice-water ratios) during soaking was confirmed by evaluating the k and n values of the Page model. These expressions were validated using acceptable R^2, *SEE*, and *RMSE*. The prediction data from this work would be useful for estimating dimensional changes during soaking and cooking quality.

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Conflict of interest

The authors declare no conflict of interest.

Author Contribution Statement

Puteri Nurain Megat Ahmad Azman: Conceptualization, developed methodology, performed methodology, performed

data collection, analyzed the data of results, and wrote the manuscript.
Rosnah Shamsudin: Conceptualization, developed methodology, supervised the work, and revised the manuscript.
Norhashila Hashim: Conceptualization, developing methodology, supervising experiments, and funding finder.
Hasfalina Che Man: Conceptualization, developed methodology, supervised the experiments.
All authors have read and agreed to the published version of the manuscript.

Abbreviations

A	glutinous rice-water ratio 1:1.1
B	glutinous rice-water ratio 1:1.3
C	glutinous rice-water ratio 1:1.5
DE	Equivalent diameter
L	Length
PA_L	Projected area
R^2	Coefficient of determination
RMSE	Root means square error
SA	Surface area
SEE	Standard error of estimate
T	Thickness
W	Width

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