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SPECIAL ISSUE ARTICLE

Kinetic Modelling During Soaking of Dried Long Grain Paddy MR297

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Abstract

This study aimed to assess the soaking behaviour of MR 297 dried paddy under two conditions: room temperature and hot water soaking at 60 °C. The experiment involved soaking dried MR297 paddy samples in water for 0.5–8 h at room temperature and 0.5–5 h for soaking at 60 °C. The water absorption of MR 297 behaved differently at two different soaking conditions. The kinetic behaviour of the soaking process was also simulated using established 25 predictive models and incorporating 5 novel models presented in this work. The comparison of all prediction models involved using three statistical measures: the coefficient of determination (R-squared), standard error of estimates (SEE), and root mean square error (RMSE). The Karizaki 10, Midilli Kucuk, Karizaki 8, Two term, and Proposed Model was determined to be the 5 of most effective predictive models for characterizing the MR297 paddy soaking behaviour at room temperature. While Cubic, Karizaki 11, Karizaki 10, Karizaki 8, and proposed model 5 provided superior predictive capabilities for soaking behaviour of MR 297 at 60 °C. Additionally, the findings of this study also indicate that the proposed models exhibit superior predictive performance compared to the convenational models employed by other researchers.

Keywords: Modelling, MR297, Paddy, Soaking

1. Introduction

Approximately 90% of the global rice production and consumption takes place in the continent of Asia. There was an increase in global rice output from 448.2 million tonnes in 2008 to 502.8 million tonnes in 2022 (Shahbandeh, 2022). The processing of rice holds significant importance in numerous locations across the globe. The local production effort has challenges pertaining to quality, as the market for locally produced rice is hindered by the presence of imported rice that obtains superior quality. A significant number of locally farmed types exhibit suboptimal milling recoveries, a high prevalence of chalkiness, and inadequate cooking qualities (Graham-Acquaah et al., 2015). MR297 is a Malaysian rice variety that is prone to experiencing a significant amount of

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broken rice grains during the milling process, as reported by the Malaysian Agricultural Research and Development Institute (MARDI) (Sunian et al., 2022). The implementation of pretreatment methods such as soaking and parboiling is a crucial approach for enhancing the quality of rice, as it effectively seals the internal cracks inside the grains (Siebenmorgen et al., 2009).

The process of paddy soaking is entangled and influenced by various elements, such as the temperature and duration of soaking, beginning moisture level, and diffusion characteristics (Oli et al., 2014). The process of soaking holds significant importance as it facilitates the increase in moisture content within the kernel by the diffusion of water (Muchlisyiyah et al., 2023). This increase in moisture ensures that the starch is adequately supplied with the necessary water for the process of gelatinization (Gariboldi, 1979). However, if the soaking temperature is excessively low, it can lead to a prolonged soaking period and result in the spoilage of paddy due to fermentation and microbial activity (Bhattacharya, 2004). The use of warm water soaking is a widely employed technique to expedite the soaking process, since it has been observed that elevating the temperature leads to an augmented rate of hydration (Kashaninejad et al., 2007).

Numerous mathematical models are employed in order to clarify and forecast the water absorption behaviour of kernels or grains, with soaking time serving as the independent variable (Balbinoti et al., 2018; Ji-u & Inprasit, 2019). The physiochemical effects of rice raw materials (paddy, rice, brown rice, milled rice and variety) on rice types observed by diverse authors differ significantly in characteristics, necessitating in-depth studies between hydration processes and the nature of raw materials (Muchlisyiyah et al., 2023) Nevertheless, there is currently no available literature regarding the impact of soaking practices on MR297 paddy. Previous research has examined the impact of soaking temperature on parboiling (Sareepuang et al., 2008). However, the present study focuses specifically on investigating the water absorption behaviour in MR297. Given the lack of available information regarding the soaking behaviour of Malaysian rice varieties, the primary objectives of this study were to investigate the soaking behaviour of MR 297 dried paddy under two distinct soaking conditions (room temperature and hot water soaking at 60 °C). Additionally, the study aimed to identify the most suitable mathematical model that accurately describes the soaking behaviour of paddy during the aforementioned conditions.

2. Materials and methods

2.1. Soaking process

MR 297 paddy was obtained from a paddy field in Tanjung Karang, Selangor, Malaysia (moisture content 19.22 ± 0.84%). The paddy was dried using sun drying for three days until the moisture content was 7.55%. The paddy was then kept in a closed container until further processing. Sixty grams of dried paddy was placed in a beaker glass with 200 ml water (Ji-u & Inprasit, 2019). The soaking was conducted at room temperature and 60 °C in a water bath. The soaked paddy was drained and blotted every soaking time using paper towels to eliminate any remaining surface moisture. The soaking at room temperature was done at 0, 0.5, 1, 2, 3, 4, 6, and 8 h; soaking at 60 °C was conducted at 0.5, 1, 1.5, 2, 3, 4, and 5 h (Rattanamechaiskul et al., 2023; Unnikrishnan et al., 2007). The equilibrium moisture content (EMC) was obtained by soaking dried paddy MR297 for 16 h for both conditions.

The moisture content of paddy refers to its ability to absorb water, and this study aimed to assess the suitability of several water absorption models in predicting the moisture content of paddy throughout the soaking process. The water absorption in paddy was conducted by measuring the rise in moisture content. The moisture content was determined by using a moisture analyser (A&D MX50, United States).

2.2. Kinetic modelling of paddy soaking process

A total of thirty consisting of twenty-five empirical models and five proposed models (as shown in Table 1) were employed to forecast the water absorption behaviour of the dried paddy MR297 during the soaking process. The moisture ratio (MR) was utilised to express the kinetics of water absorption, as per the equation provided (Chakkaravarthi et al., 2008):

$$MR = \frac{M_t - M_o}{M_e - M_o}$$

Where.

M_o= Initial moisture content; M_e= Moisture content in equilibrium; M_t= Moisture in t.

2.3. Statistical parameters

The soaking models shown in Table 1 were evaluated in order to determine the most effective predictive model for predicting the soaking kinetics of

Table 1. Mathematical formulas considered kinetics.

Model	Number of constants	Mathematical Model	References
Linear	2	$MR = a + bt$	Azman et al. (2020)
Quadratic	3	$MR = a + bt + ct^2$	Azman et al. (2020)
Cubic	4	$MR = a + bt + ct^2 + dt^3$	Azman et al. (2020)
Exponential	2	$MR = a\ exp\ (kt)$	Azman et al. (2020)
S-curve	2	$MR = a + \frac{b}{t}$	Azman et al. (2020)
Power	2	$MR = at^b$	Azman et al. (2020)
Peleg	2	$M_t = M_0 + \frac{t}{k_1 + k_2\ t}$	Yadav & Jindal (2007)
Lewis	1	$MR = exp\ (-kt)$	Ji-u & Inprasit (2019)
Page	2	$MR = exp\ (-k_0 t^n)$	Ji-u & Inprasit (2019)
Modified Page 1	2	$MR = exp\ [(-kt)^n]$	Karizaki (2016)
Modified Page 2	2	$MR = exp\ [-(kt)^n]$	Ji-u & Inprasit (2019)
Handerson & Pabis	2	$MR = a\ exp\ (-k_0 t)$	Ji-u & Inprasit (2019)
Wang & Singh	2	$\mathrm{MR} = 1 + \mathrm{at} + \mathrm{bt}^2$	Karizaki (2016)
Logarithmic	3	$MR = a\ exp(-kt) + c$	Karizaki (2016)
Diffusion	3	$MR = a\ exp(-kt) + (1-a)\ exp(-kbt)$	Karizaki (2016)
Verma	3	$MR = a\ exp(-kt) + (1-a)\ exp(-gt)$	Karizaki (2016)
Two term	4	$MR = a\ exp(-k_0 t) + b\ exp(-k_1 t)$	Karizaki (2016)
Two term exponential	2	$MR = a\ exp(-kt) + (1-a)\ exp(-kat)$	Ji-u & Inprasit (2019)
Jenna Das	4	$MR = a\ exp(-kt + b\sqrt{}t) + c$	Karizaki (2016)
Midilli Kucuk	4	$MR = a\ exp\ [(-kt)^n] + bt$	Karizaki (2016)
Vega Lemus	2	$\mathrm{MR} = (\mathrm{a} + \mathrm{bt})^2$	Karizaki (2016)
Karizaki 8	4	$MR = at^2 + bt^{-1} + cLn(t) + d$	Karizaki (2016)
Karizaki 10	4	$MR = aexp(t) + bLn(t) + ct + d$	Karizaki (2016)
Karizaki 11	4	$MR = \frac{\exp\ (at+b)}{t^c}$	Karizaki (2016)
Karizaki 13	3	$MR = exp\ [at^2 + bt + c]$	Karizaki (2016)
Proposed Model 1	4	$MR = a\ Ln(t) + b\ \exp\ (t^{-1}) + c\ \exp\ (t^{-2}) + d\ \exp\ (t^{-3})$	Our study
Proposed Model 2	4	$MR = a + b\ exp(t) + \exp(c\ exp(t)) + d\ t$	Our study
Proposed Model 3	4	$MR = \exp(a + bt + ct^2 + dt^3)$	Our study
Proposed Model 4	3	$MR = exp(a + bt) + c$	Our study
Proposed Model 5	4	$MR = a + bt^{-1} + ct^{-2} + dt^{-3}$	Our study

paddy MR297. The major criterion for determining the optimum equation was the coefficient of determination, written as R^2 (R-squared). The higher values of R^2 were deemed to indicate a strong level of fit. Furthermore, the selection of the best fit was made by determining additional statistical measures, including the standard error of estimate (SEE) and root mean square error (RMSE). Lower values of the SEE and RMSE imply a higher level of fit quality between mathematical models and experimental data.

3. Results and discussion

3.1. Soaking process of paddy MR297

The kinetics for MR 297 paddy soaking in room temperature and hot water soaking 60 °C is transformed in to graph between -Ln MR (-Ln $\frac{Mt-Mo}{Me-Mo}$) and time of soaking (hour) as presented in Fig. 1. The graph represents the dimensionless MR against time during soaking of paddy in two different conditions. There is a linear relationship between Ln MR with time (hour) of soaking. The slope of the linear relationship would represent the moisture diffusivity of the soaking process (Karizaki, 2016). The greater the slope, the greater the moisture diffusivity and faster the soaking process. Fig. 1 shows that the slope of graph of Ln MR-time of the soaking at 60 °C is steeper than soaking at room temperature. It means that the soaking process at

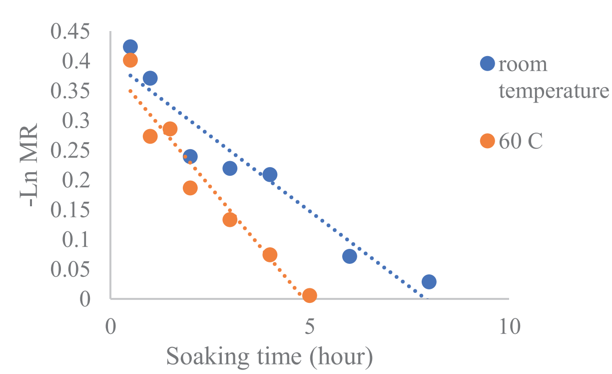

Fig. 1. The dimensionless MR over time in paddy soaking in room temperature and 60 °C.

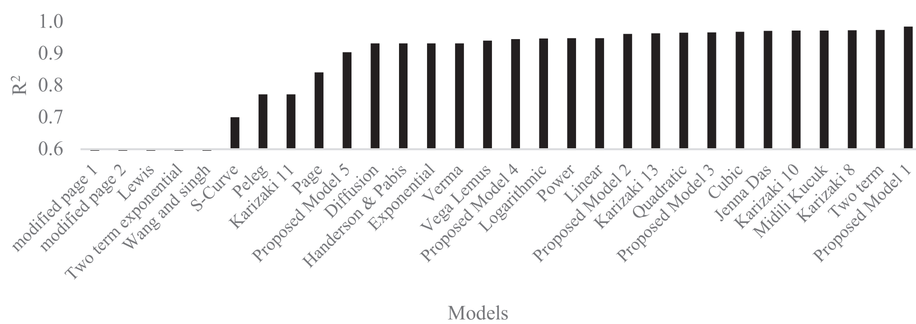

Fig. 2. The R^2 for mathematical models in paddy soaking in room temperature.

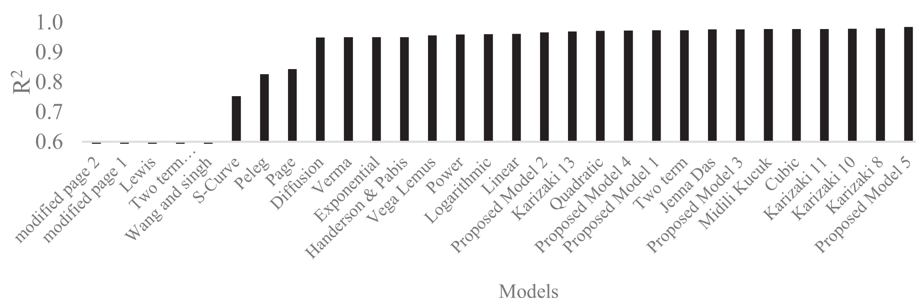

Fig. 3. The R^2 for mathematical models in paddy soaking in 60 °C.

60 °C requires a shorter period than soaking at room temperature. This finding is in agreement with the results of the previous study, they also found that the increase of temperature would result in the increase of the diffusivity during the soaking process (Bello et al., 2004; Ji-u & Inprasit, 2019; Karizaki, 2016). Moisture diffusivity during the soaking process is temperature dependent (Karizaki, 2016).

3.2. Kinetic modelling of paddy soaking process

The MR data obtained throughout the soaking process of MR297 paddy at room temperature and hot water 60 °C were subjected to fitting procedures using 30 different mathematical models (25 was empirical models adapted from literature and 5 was the proposed models). The key criterion for selecting the most suitable mathematical models to describe the soaking behaviour of rice was based on the coefficient of determination (R^2) values. A higher R^2 value indicates a stronger degree of fit between the observed data and the fitted regression model. The R^2 values for all mathematical models are provided in Figs. 2 and 3, corresponding to soaking at room temperature and hot water 60 °C, respectively.

Based on the statistical findings derived from the analysis of 30 predictive models, a selection was made of the twenty models that exhibited the highest R-squared values. These chosen models were deemed representative of the MR 297 dried paddy soaking behaviour of both at room temperature and hot water 60 °C. In a comparative manner, Figs. 4 and 5 present the statistical parameters of SEE and RMSE for the 20 models in relation to the soaking process at room temperature and hot water 60 °C, respectively. The acquired results for all 20 predictive models representing the dried MR297 paddy soaking process at room temperature and hot

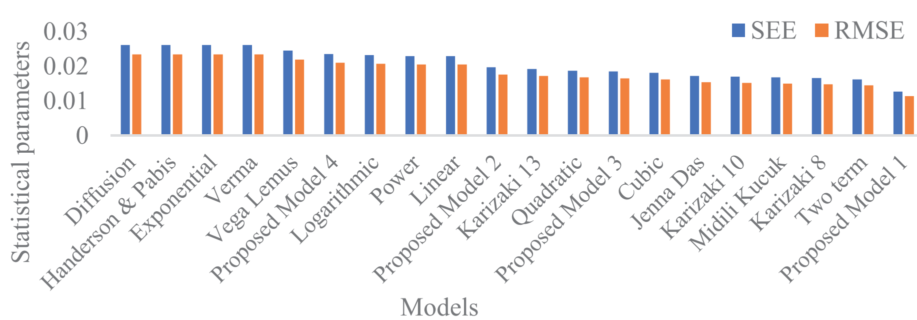

Fig. 4. The statistical parameters SEE and RMSE for top 20 mathematical models in paddy soaking in room temperature.

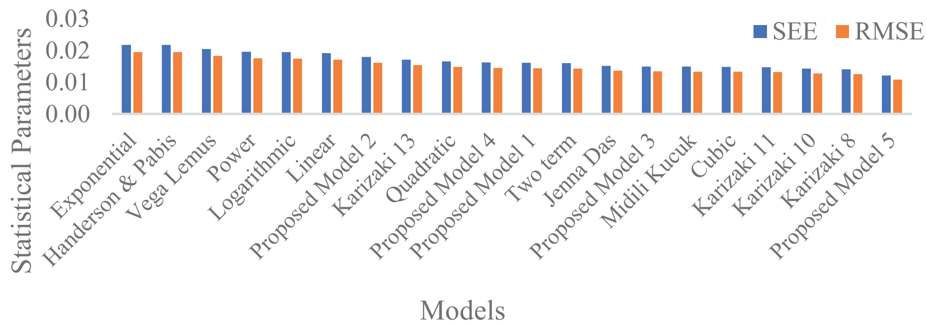

Fig. 5. The statistical parameters SEE and RMSE for top 20 mathematical models in paddy soaking in 60 °C.

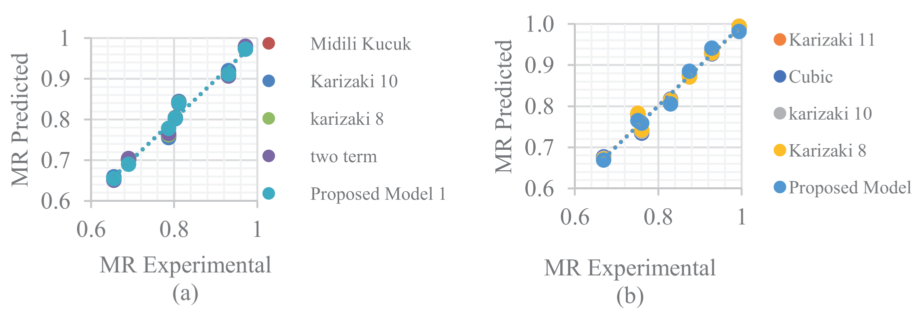

Fig. 6. Comparison of predicted with experimental MR in paddy soaking at (a) room temperature (b) paddy soaking in 60 °C.

water 60 °C of SEE and RMSE as depicted in Fig. 4. Figs. 4 and 5 illustrates that both soaking conditions behaved and fit differently in the models. The Karizaki 10, Midilli-kucuk, Karizaki 8, Two term, and Proposed Model 1 had superior predictive performance compared to other models in the context of the soaking process of dried paddy at the room temperature (Fig. 4). Among the several models considered for soaking at hot water 60 C the suggested Cubic, Karizaki 11, Karizaki 10, Karizaki 8, and proposed model 5 (as depicted in Fig. 5), exhibited the most favourable performance.

The validation of the optimal models was conducted by assessing the agreement between the projected MR values and the corresponding experimental data for both soaking at room temperature (Fig. 6a) and soaking at hot water 60 °C (Fig. 6b) paddy MR297 during the soaking process. The observed and anticipated values were distributed along a linear trend in the depicted graphs. As evident from Fig. 6a, the proposed model 1 exhibited the most accurate prediction of the soaking behaviour at room temperature. Fig. 6b illustrates the most accurate prediction for soaking at 60 °C at proposed model 5.

4. Conclusions

This study aimed to evaluate the behaviour of the soaking process of MR297 dried paddy at room temperature and at hot water soaking 60 °C. The calculation procedures for predicting the soaking behaviour relied on the utilization of dimensionless MR values that vary with time. The soaking characteristics of rice were also anticipated through the application of diverse 30 mathematical models (25 empirical models and 5 proposes models). Out of the 30 predictive models that were subjected to comparative analysis based on statistical characteristics R^2, SEE, and RMSE, it was found that both the soaking procedures behaved differently and fit to the different models. The 5 highest coefficient determination for soaking at room temperature was Karizaki 10, Midilli kucuk, Karizaki 8, Two term, and Proposed Model. The best fit models for the soaking at soaking 60 °C was Cubic, Karizaki 11, Karizaki 10, Karizaki 8, and proposed model 5. The utilization of proposed models has the potential to be advantageous in the design and operation of soaking procedures.

Authors' contributions

Jhauharotul Muchlisyiyah designed and wrote the manuscript. Writing and editing by Jhauharotul Muchlisyiyah and Rosnah Shamsudin. Rosnah Shamsudin, Radhiah Shukri, Roseliza Kadir Basha. Syahmeer How, and Masmunira Rambli revised the manuscripts. Rosnah Shamsudin supervised the project. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

We declare that there is no conflict of interest in the publication of this article.

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References

Azman, P. N. M. A., Shamsudin, R., Man, H. C., & Ya'acob, M. E. (2020). Some physical properties and mass modelling of pepper berries (*Piper nigrum* l.), variety kuching, at different maturity levels. *Processes, 8*(10), 1–15. https://doi.org/10.3390/pr8101314

Balbinoti, T. C. V., Jorge, L. M. de M., & Jorge, R. M. M. (2018). Modeling the hydration step of the rice (Oryza sativa) parboiling process. *Journal of Food Engineering, 216*, 81–89. https://doi.org/10.1016/j.jfoodeng.2017.07.020

Bello, M., Tolaba, M. P., & Suarez, C. (2004). Factors affecting water uptake of rice grain during soaking. *LWT - Food Science and Technology, 37*(8), 811–816. https://doi.org/10.1016/j.lwt.2004.02.014

Bhattacharya, K. R. (2004). Chapter 13: Parboiling of rice. In *Rice: Chemistry and Technology* (pp. 329–404). American Association of Cereal Chemists, Inc. https://doi.org/10.1094/1891127349.013.

Chakkaravarthi, A., Lakshmi, S., Subramanian, R., & Hegde, V. M. (2008). Kinetics of cooking unsoaked and presoaked rice. *Journal of Food Engineering, 84*(2), 181–186. https://doi.org/10.1016/j.jfoodeng.2007.02.061

Gariboldi, F. (1979). *Rice testing methods and equipment* (18th ed.). FAO.

Graham-Acquaah, S., Manful, J. T., Ndindeng, S. A., & Tchatcha, D. A. (2015). Effects of soaking and steaming regimes on the quality of artisanal parboiled rice. *Journal of Food Processing and Preservation, 39*(6), 2286–2296. https://doi.org/10.1111/jfpp.12474

Ji-u, P., & Inprasit, C. (2019). Effect of soaking conditions on properties of Khao Dawk Mali 105. *Agriculture and Natural Resources, 53*(4), 378–385. https://doi.org/10.34044/j.anres.2019.53.4.08

Karizaki, V. M. (2016). Kinetic modeling and determination of mass transfer parameters during cooking of rice. *Innovative Food Science & Emerging Technologies, 38*, 131–138. https://doi.org/10.1016/j.ifset.2016.09.017

Kashaninejad, M., Maghsoudlou, Y., Rafiee, S., & Khomeiri, M. (2007). Study of hydration kinetics and density changes of rice (Tarom Mahali) during hydrothermal processing. *Journal of Food Engineering, 79*(4), 1383–1390. https://doi.org/10.1016/J.JFOODENG.2006.04.019

Muchlisyiyah, J., Shamsudin, R., Hashim, N., Kadir, R., & Che Man, H. (2023a). Kinetics of water absorption during rice soaking: A review. *Advances in Agricultural and Food Research Journal, 4*(2). https://doi.org/10.36877/aafrj.a0000375

Muchlisyiyah, J., Shamsudin, R., Kadir Basha, R., Shukri, R., How, S., Niranjan, K., & Onwude, D. (2023b). Parboiled rice processing method, rice quality, health benefits, environment, and future perspectives: A review. *Agriculture, 13*(7), 1390. https://doi.org/10.3390/agriculture13071390

Oli, P., Ward, R., Adhikari, B., & Torley, P. (2014). Parboiled rice: Understanding from a materials science approach. *Journal of Food Engineering, 124*, 173–183. https://doi.org/10.1016/j.jfoodeng.2013.09.010

Rattanamechaiskul, C., Junka, N., & Prakotmak, P. (2023). Modeling and optimization of moisture diffusion of paddy and brown rice during thermal soaking. *Journal of Food Process Engineering*. https://doi.org/10.1111/jfpe.14302

Sareepuang, K., Siriamornpun, S., Wiset, L., & Meeso, N. (2008). Effect of soaking temperature on physical, chemical and cooking properties of parboiled fragrant rice research unit of drying Technology for agricultural products. *World Journal of Agricultural Sciences, 4*(4), 409–415.

Shahbandeh, M. (2022). *World production volume of milled rice from 2008/2009 to 2021/2022*. https://www.statista.com/Statistics/271972/World-Husked-Rice-Production-Volume-since-2008/.

Siebenmorgen, T. J., Saleh, M. I., & Bautista, R. C. (2009). Milled rice fissure formation kinetics. *Transactions of the ASABE, 52*(3), 893–900. https://doi.org/10.13031/2013.27378

Sunian, E., Ramli, A., Jamal, M. S., Saidon, S. A., & Kamaruzaman, R. (2022). Development of high yielding varieties for food sustainability production. *Buletin Teknologi MARDI Bil, 30*, 83–97 (2022) Khas Kolokium Pembaikbakaan Tanaman.

Unnikrishnan, K. R., Viraktamath, C. S., Krishnamurthy, H., & Bhattacharya, K. R. (2007). Parboiling of paddy by simple soaking in hot water. *International Journal of Food Science and Technology, 17*(4), 499–506. https://doi.org/10.1111/j.1365-2621.1982.tb00205.x

Yadav, B. K., & Jindal, V. K. (2007). Modeling changes in milled rice (Oryza sativa L.) kernel dimensions during soaking by image analysis. *Journal of Food Engineering, 80*(1), 359–369. https://doi.org/10.1016/J.JFOODENG.2006.06.005