Impingement drying of germinated brown rice varieties at intermediate temperatures: drying kinetics and analysis of quality

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Summary

Germinated brown rice is an important source of γ-aminobutyric acid (GABA). In this study, the impingement drying conditions were carried out at various drying temperatures at air velocity 16 $m \cdot s^{-1}$. Impingement drying is an effective technique that accelerates heat transfer and reduces the drying time. Parboiled germinated paddy drying data of two rice varieties were statistically simulated by various drying kinetics modeling. The predicted data using the Midilli drying kinetics model were found to best fit all experimental data. The effective moisture diffusivity (D_{eff}) of the parboiled germinated paddy varieties was determined by the second Fick's law of diffusion and results showed that the D_{eff} value increased with the drying temperature. The D_{eff} value of the short-grain parboiled germinated paddy variety was relatively high compared to the long-grain variety. Chemical quality analysis of biologically active compounds as well as determination of antioxidant activity were carried out. The chemical quality of both rice varieties increased after germination, whilst the steaming and drying processes insignificantly affected it. Our results on impingement drying suggested that the suitable drying temperature was 90 °C due to reduction of the drying time, energy saving and causing less chemical disintegration.

Keywords

antioxidant; chemical quality; γ-aminobutyric acid; germinated brown rice; impingement drying

Rice is the main staple food of more than a half of the world's population. It is mostly consumed in the form of milled rice. Nowadays, whole-grain food such as whole-grain bread or crackers, oatmeal, hulled barley or brown rice are known for their health-promoting properties and nutritional value. The brown rice contains more nutritional components than ordinary white rice because the outer bran layer of the brown rice grain is rich in fibre, iron, vitamins and minerals which are not removed during the milling process. However, cooked brown rice is sensorically slightly hard compared to the milled rice and it cannot be stored for a long period because of deterioration. Fortunately, the change of staple food from milled rice and brown rice to germinated brown rice can maintain and promote a healthy quality for life. Furthermore, germinated brown rice is suitable to provide nutrients required for good health due to its high nutritional values and beneficial physiological effects [1]. During the germination process, essential nutrients useful for a human, such as γ-aminobutyric acid (GABA) and bioactive compounds are produced. The contained GABA is a substance that has been suggested as stress–reducing, sleep–enhancing and preventing brain damage that causes high levels of memory loss or Alzheimer's disease [2].

The germinated brown rice production consists of several steps. The first step is to soak the pad-

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dy in water for 24 h at room temperature. After that, the paddy sample is removed from water and germinated in the dark for 48 h. Then, germinated paddy is steamed to stop growing and to devitalize microorganisms. Finally, germinated paddy is dried to a safe moisture content suitable for long shelf life storage and for maintaining the quality.

Drying plays a vital role in the production of germinated paddy because it reduces the moisture to a suitable, safe level. It is imperative to preserve the quality of germinated brown rice. A traditional method of drying germinated brown rice is by sun drying. The sun drying is a low-cost energy heating source, however, there are drawbacks relating to this method [3]. Sun-drying cannot be performed during the wet season. Therefore, various drying techniques such as hot air drying or steam drying, moving-bed drying (such as fluidized-bed drying, spouted-bed drying or impingement drying), and fixed-bed drying (such as tray drying or cabinet drying) have been introduced for drying of products. The hot air drying technique is widely used in drying applications owing to its several advantages, including simplicity, low maintenance requirement, a wide range of drying temperatures and high efficiency [4]. However, hot air impingement drying is a highly effective drying method. It is a novel alternative for removing moisture from particulate material. At impingement drying, air impinges on the product surface at high velocity, removes the thermal boundary layers and increases the rate of heat and mass transfer, which reduces the drying time. Several studies used impingement drying techniques for food drying. Deng et al. [5] studied the drying kinetics and quality of orange peel with a hot air impingement dryer. Wang et al. [6] focused the research on the drying kinetics, physico-chemical properties, microstructure and energy consumption of impingement drying of potato cubes. Qiu et al. [7] analysed the degradation kinetics and antioxidant capacity of dried purple potato slices using the air-impingement jet drying technique.

However, drying is intricate to control the process and to achieve the required quality parameters. This may be mainly attributed to the lack of reliable information on suitable drying kinetics and drying temperature of germinated brown rice during hot air drying. A priority aspect in drying technology is to study the kinetics of drying using mathematical models that can help us in the drying process and to obtain high quality products [5]. Mathematical modelling of the drying curve can be studied by drying parameters and designing or improving the drying systems [8]. By mathematical modelling, a series of mathematical equations is obtained that can satisfactorily explain the drying process [9]. Several mathematical models have been employed to explain the drying process of agricultural products such as mushrooms [10], banana and peach [11] or parboiled paddy [12].

Unsuitable drying conditions may lead to various adverse effects on the quality of germinated brown rice. Therefore, this study was aimed to find the optimum drying temperature of impingement drying and to examine the effect of temperature on the drying kinetics and quality of germinated brown rice products.

MATERIALS AND METHODS

Materials

Sang Yod and Chaing Phatthalung paddy varieties were provided from the Rice Research Institute in Phatthalung province (Phatthalung, Thailand).

Hot air impingement drying

A schematic diagram of hot air impingement dryer is shown in Fig. 1. It consisted of a drying chamber with an inner diameter of 30 cm and height of 50 cm, a 10 kW electrical heater, a 0.75 kW blower, and a 2 cm diameter of a nozzle with a total of 10 nozzles.

Preparation of germinated brown rice

The two paddy varieties were soaked with tap water for 24 h at 30 °C. At every 4 h, the soaked water was replaced with the new water to avoid fermentation. For germination, the paddy sample was removed and then put into a box that was covered with a moistened thin cloth and close the lid of the box for 48 h [13]. At every 6 h, the paddy sample was sprayed with water to add moisture. During the germination time of 48 h, a small sprout of rice germ with a length of about 0.5–1 mm was formed. The germinated paddy sample was steamed at 95 ± 5 °C for 30 min. The moisture content of the germinated paddy was determined using the AOAC method 977.11 [14]. The paddy samples for this experiments were prepared and classified as 3 types which are brown rice, germinated paddy dried in shade and parboiled germinated paddy (PGP) dried with hot air impingement at various temperatures.

Drying process

The germinated paddy samples were dried in the hot air impingement dryer simultaneously at temperatures of 60, 70, 80 and 90 °C, respectively, with a superficial velocity of 16 $m \cdot s^{-1}$. Samples of

700 g with the average initial moisture content of 53 ± 2 % dry-basis (DB) were dried until the final moisture content of sample reached 22 ± 3 % DB. Samples were taken from the drying chamber to determine the quality at a specified time. After hot air impingement drying, the sample was tempered instantly in an insulated ware for 30 min [15]. Then, the samples were ventilated by ambient air until the product moisture content was approximately 13–15 % DB. The dried samples were analysed for quality.

Mathematical drying modelling

The models for hot air impingement drying of various food products are widely published. However, only a few are reported as suitable for modelling impingement drying kinetics of germinated paddy. Six different mathematical models shown in Tab. 1 were used to determine the drying kinetics of high moisture germinated paddy using the impingement drying technique. To evaluate the moisture ratio of the germinated paddy during the drying experiment, the moisture ratio (*MR*) defined in Eq. 1 was employed:

$$MR = \frac{M_t - M_{eq}}{M_{in} - M_{eq}} \tag{1}$$

where M_t is the moisture content at time t, M_{eq} is the equilibrium moisture content and M_{in} is the initial moisture content.

For impingement drying, M_{eq} is relatively small compared to M_i [16]. Therefore, M_{eq} can be ignored and Eq. 1 can be simplified as Eq. 2:

$$MR = \frac{M_t}{M_{in}} \tag{2}$$

Effective diffusivity

The drying process of food materials usually occurs in the falling rate period, implying that moisture transfer during drying is restricted or controlled by diffusion within the material. Fick's second law can explain the drying course of germinated paddy. The solution of Fick's second law equation can be given as Eq. 3 under the assumption that the paddy kernel has infinite cylindrical shape, constant moisture diffusivity and constant temperature [16].

$$MR = \left(\frac{8}{\pi^2}\right)\sum_{n=0}^{\infty}\frac{4}{\lambda_n^2}\exp\left(-\frac{\lambda_n^2 D_{eff}t}{r_0^2}\right)\times \\ \times\sum_{m=1}^{\infty}\frac{1}{(2m+1)^2}\exp\left(-\frac{\pi^2(2m+1)^2 D_{eff}t}{4L^2}\right) \tag{3}$$

where λ_n is the root of a Bessel function of the

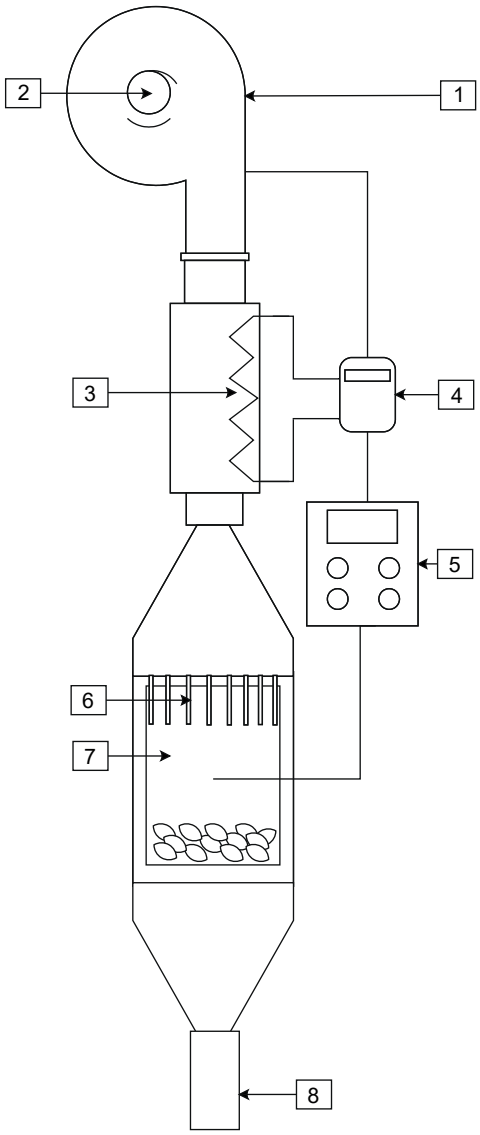

Fig. 1. A schematic diagram of the hot air impingement dryer.

1 – blower, 2 – air inlet, 3 – heater, 4 – watt hour meter, 5 – temperature control, 6 – nozzle, 7 – drying chamber (temperature is measured in the middle of chamber), 8 – air outlet.

Tab. 1. Empirical thin-layer drying model for parboiled germinated paddy [8].

Name of the model	Model equation
Page	$MR = \exp(-kt^n)$
Logarithmic	$MR = a\exp(-kt) + b$
Wang and Singh	$MR = 1 + at + bt^2$
Newton	$MR = \exp(-kt)$
Henderson and Pabis	$MR = a\exp(-kt)$
Midilli et al.	$MR = a\exp(-kt^n) + bt$

MR – moisture ratio (in percent); *t* – time (in minutes); *a*, *b*, *n* and *k* – constants in thin-layer drying equation, which are calculated by non-linear regression analysis.

first kind and zero-order, r is the radius of the paddy kernel (in metres). The radius (r) of the Sang Yod paddy kernel and Chaing Phatthalung paddy kernel is 0.85×10^{-3} m and 0.90×10^{-3} m, respectively. D_{eff} is effective moisture diffusivity (in square meter per second), t is time (in minutes), L is the grain length (in metres). The Sang Yod paddy and Chaing Phatthalung paddy have grain length 9.3×10^{-3} m and 9.8×10^{-3} m, respectively. If only $n = (1, 2)$ and $m = (0, 1)$ are considered, the expansion of Eq. 3 can be shown as follws:

$$MR = 0.5619\exp(-5.7802N_{Fi} - 2.4649N_{Fo}) + \\ + 0.0623\exp(-5.7802N_{Fi} - 22.207N_{Fo}) + \\ + 0.1064\exp(-30.47N_{Fi} - 2.4649N_{Fo}) \quad (4)$$

where N_{Fi} is Fick number, and N_{Fo} is Fourier number.

$$N_{Fi} = \frac{D_{eff}t}{r^2} \quad (5)$$

$$N_{Fo} = \frac{D_{eff}t}{L^2} \quad (6)$$

When the drying time is large, the last three terms are relatively small compared with the first term [17]. Therefore, only the first term can be considered, resulting in the natural log of Eq. 7 that can be written as:

$$\ln(MR) = \ln(0.5619) - \\ -\left(\frac{5.7802}{r^2} + \frac{2.4649}{L^2}\right)D_{eff}t \quad (7)$$

To calculate D_{eff}, the method of the slope was employed. In this case, the slope can be obtained from the graph by plotting the ln(MR) value on the y–axis and the drying time on the x–axis and, therefore, the effective moisture diffusivity can be determined using Eq. 8.

$$D_{eff} = \frac{-S}{\left(\frac{5.7802}{r^2} + \frac{2.4649}{L^2}\right)} \quad (8)$$

where S is slope.

According to Xing–Jun et al. [16], temperature dependence of D_{eff} can be computed using an Arrhenius relationship, as shown in Eq. 9:

$$D_{eff} = D_0\exp\left(-\frac{E_a}{RT}\right) \quad (9)$$

where D_0 is the pre-exponential factor of the Arrhenius equation, E_a is the activation energy (in joules per moles), R is the universal gas constant (8.314 $J{\cdot}mol^{-1}K^{-1}$) and T is the absolute air temperature (in kelvins). The activation energy is determined from the slope of the plot of ln(D_{eff}) against the inverse of the temperature.

Chemicals and reagents

Sodium carbonate (Na_2CO_3), sodium nitrite ($NaNO_2$), borate buffer pH 9.0, standards of catechin and vanillin, ferric chloride ($FeCl_3$), standard of γ-aminobutyric acid (GABA), 2,4,6–tripyridyl–*s*–triazine (TPTZ), aluminium chloride ($AlCl_3$), 2,2-diphenyl-1-picrylhydrazyl (DPPH), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) and phenol were obtained from Sigma–Aldrich (St. Louis, Missouri, USA). Sodium hydroxide (NaOH), sodium hypochlorite (NaOCl), methanol, ethanol and hydrochloric acid (HCl) were obtained from RIC Labscan (Bangkok, Thailand). All chemicals and reagents used in the study were of analytical grade.

Extraction

Samples extraction was carried out using 70% ethanol as a solvent at a ratio of 1 : 10 (v/v) by following the method of Thammapat et al. [18]. Samples were shaken at 25 °C in a shaking incubator at 0.504 ×g for 16 h. Then, the samples were centrifuged at 2 500 ×g for 20 min to separate the supernatants. The residues were re-extracted under the same conditions, and supernatants from both extractions were combined.

Total proanthocyanidin content

The total proanthocyanidin content (*TPAC*) was determined by using the modified method of Hu et al. [19]. A sample of 0.5 g was extracted three times with 15 ml of methanol with 1 $mol{\cdot}l^{-1}$ HCl (85 : 15, v/v) by a shaker in the dark and then centrifuged for 15 min at 4 100 ×g. Briefly, 0.6 ml of sample extracts or standard solutions were mixed with 1.5 ml of 1% vanillin solution in methanol. The mixture reacted at room temperature (about 30 °C) in a water bath for 20 min and then 1.5 ml of a mixture of methanol with sulfuric acid (4 : 1, v/v) was added. The absorbance at a wavelength of 500 nm was measured using UV/Vis spectrophotometer Libra S22 (Biochrom, Cambridge, United Kingdom). Extracts treated with 99.9% methanol were used as blank to eliminate interferences. The results were expressed as grams of catechin equivalent (CE) per kilogram of dry rice flour.

Total phenolics content

Total phenolics content (*TPC*) of rice extracts was determined using the Folin-Ciocalteu colorimetric method by following the method of Thammapat et al. [18]. Concisely, extract solu-

tion (200 μl) was added to a test tube containing 800 μl of 10% Folin-Ciocalteu reagent and the tubes were vortexed for 1 min. A volume of 2 ml of 0.75 g·l^{-1} sodium carbonate solution was added to each tube and the tubes were vortexed once again for 30 s. Then, the mixture was made up to 5 ml with deionized water. After that, the mixed solution was kept in the dark at room temperature (about 30 °C) for 2 h. The absorbance was measured at 760 nm using UV/vis spectrophotometer. Gallic acid was used as a standard. The result was expressed as grams of gallic acid equivalents (GAE) per kilogram of sample.

Total flavonoids content

Total flavonoids content (*TFC*) of rice extracts was determined using the modified method of Matić et al. [20]. Briefly, 0.5 ml of extract solution was mixed with 3 ml of deionized water, 0.3 ml of 5% $NaNO_2$ and then incubated for 5 min. After adding 0.6 ml of 10% $AlCl_3$ and allowing 5 min of reaction, 2 ml of 0.1 mol·l^{-1} NaOH was added. The absorbance at 510 nm was measured using UV/Vis spectrophotometer. Catechin was used as a standard. *TFC* was expressed as grams of catechin equivalents (CE) per kilogram of sample.

DPPH radical-scavenging activity

The DPPH radical-scavenging activity was determined by following the modified method of Hu et al. [19]. Briefly, 1 ml of extract solution was mixed with 5 ml of 0.1 mmol·l^{-1} DPPH solution. After incubating in the dark for 30 min, the absorbance at 517 nm was measured using UV/Vis spectrophotometer. DPPH scavenging (*SC*) was calculated using Eq. 10 and expressed in percent:

$$SC = \left(1 - \frac{A}{A_0}\right) \times 100 \qquad (10)$$

where A is absorbance of sample and A_0 is absorbance of blank.

Ferric reducing antioxidant power

The ferric reducing antioxidant power (FRAP) was determined by using the method of Benzie and Strain [21]. Concisely, FRAP reagent freshly prepared (25 ml of 0.1 mol·l^{-1} acetate buffer pH 3.6; 2.5 ml of 0.02 mol·l^{-1} $FeCl_3$ and 2.5 ml of a 0.01 mol·l^{-1} TPTZ solution in 0.04 mol·l^{-1} HCl) was incubated for 4 min at 37 °C. After that, extracts (0.1 ml) and FRAP reagent (4 ml) were added to a 10 ml volumetric flask, and the volume was adjusted with deionized water. The mixed solutions were kept for 20 min at room temperature (about 30 °C). The absorbance at 593 nm was measured against a reagent blank (4 ml of FRAP reagent, volume adjusted to 10 ml with distilled water) and a standard curve was produced using Trolox. FRAP was expressed as grams of Fe^{2+} equivalents per kilograms of dry flour.

γ-Aminobutyric acid content

GABA analysis was performed according to the procedure of Khantarate et al. [22] with some modifications. Germinated brown rice was mashed and sifted through a 11 μm sieve, 3 g of the rice flour were mixed with 30 ml of 80% (v/v) ethanol. The mixture was shaken for 24 h and filtered through Whatman paper No. 1 (Whatman, Maidstone, United Kingdom). The residue was re-extracted using the same method. The collected supernatant was dried with an evaporator at 40 °C under vacuum. The dried sample was dissolved in 3 ml of deionized water. Then, 0.2 ml of the solution obtained was added to a test tube followed by 0.2 ml borate buffer and 1 ml of 6% phenol. Subsequently, the test tube was shaken and cooled in an ice bath for 5 min. Then, 0.4 ml of 75 g·l^{-1} NaOCl was added to the test tube. Finally, it was brought to boil in a boiling water bath for 10 min and then cooled in an ice bath for 5 min. The absorbance was measured at 630 nm using UV/Vis spectrophotometer.

Statistical analyses

Quality data, including *TPAC, TPC, TFC*, antioxidant activity and GABA content, were analysed by one-way analysis of variance (ANOVA). Data from all analyses were obtained in triplicates and the results were expressed as mean ± standard deviation (*SD*). Scheffe's multiple range test was used to establish differences among mean values at a confidence level of 95 %. All statistical calculations were performed using SPSS software, (SPSS, Chicago, Illinois, USA).

RESULTS AND DISCUSSION

Empirical drying equation

Experimental results regarding moisture ratio at drying the germinated rice by impingement drying at temperatures of 60–90 °C showed that moisture ratio decreased with drying time (Fig. 2). When the drying temperatures were considered, the results showed that when a higher drying temperature was used, moisture ratio decreased faster. On the opposite, when a lower drying temperature was employed, a longer drying time was necessary. Due to the high temperature resulting in the different temperature gradient between the

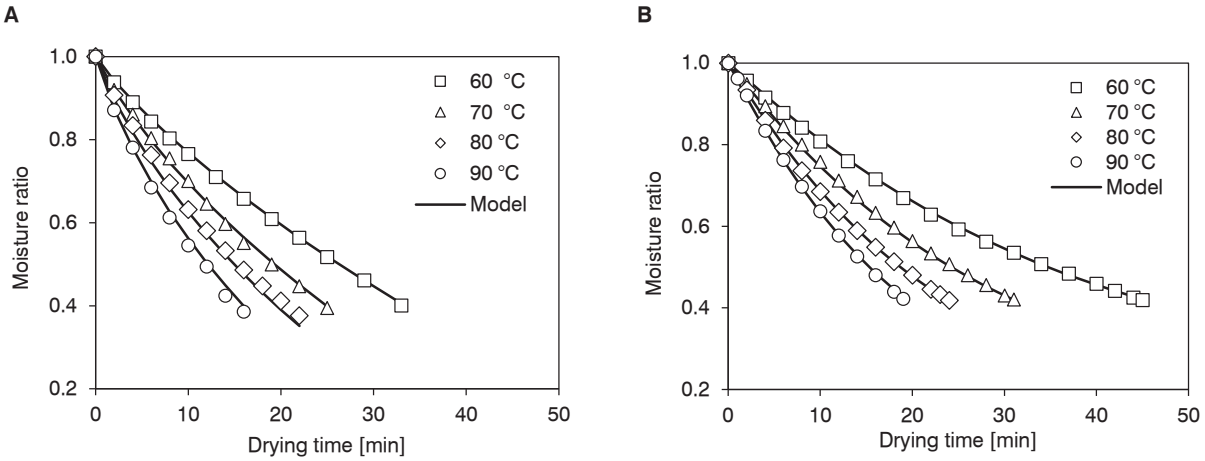

Fig. 2. Comparison of the experimental and predicted moisture ratio (Midilli model) at drying temperatures of 60–90 °C.

A – Sang Yod rice variety, B – Chaing Phatthalung rice variety.

Tab. 2. Statistical parameters of models describing the drying process of germinated brown rice.

Model	Content	R^2	*RMSE*
Germinated Sang Yod rice variety			
Page	$k = 0.301 \exp\left(\frac{1318.54}{RT}\right), n = 1.011$	0.9945	0.0120
Logarithmic	$k = 0.302 \exp\left(\frac{1309.72}{RT}\right), a = 1.00, c = -0.003$	0.9965	0.0116
Wang and Singh	$a = -0.270 \exp\left(\frac{1266.99}{RT}\right), b = 0.023 \exp\left(\frac{2478.91}{RT}\right)$	0.9947	0.0118
Newton	$k = 0.303 \exp\left(\frac{1304.29}{RT}\right)$	0.9945	0.0121
Henderson and Pabis	$k = 0.304 \exp\left(\frac{1304.07}{RT}\right), a = 1.00$	0.9945	0.0119
Midilli et al.	$k = 0.419 \exp\left(\frac{1352.94}{RT}\right), a = 1.00, b = -0.005, n = 0.851$	0.9972	0.0080
Germinated Chaing Phatthalung rice variety			
Page	$k = 335.34 \exp\left(\frac{26550.59}{RT}\right), n = 0.97$	0.9978	0.0088
Logarithmic	$k = 546.72 \exp\left(\frac{27706.05}{RT}\right), a = 0.89, c = 0.11$	0.9987	0.0068
Wang and Singh	$a = -163.14 \exp\left(\frac{24791.14}{RT}\right), b = 1728.55 \exp\left(\frac{44530.96}{RT}\right)$	0.9982	0.0081
Newton	$k = 472.26 \exp\left(\frac{27816.80}{RT}\right)$	0.9975	0.0095
Henderson and Pabis	$k = 469.22 \exp\left(\frac{27817.89}{RT}\right), a = 1.00$	0.9975	0.0093
Midilli et al.	$k = 0.201 \exp\left(\frac{1107.27}{RT}\right), a = 1.00, b = 0.002, n = 1.025$	0.9995	0.0043

a, b, c, k – constants in thin-layer drying equation, *R* – gas constant (8.314 J.mol^{-1}K^{-1}), *T* – the temperature of drying (in kelvins).

sample and air in the oven, there was an increase in the heat transfer [16].

Fig. 2 depicts the plots of the variations of the experimental and the predicted moisture ratio of the best model, Midilli, with the drying times of germinated rice. From the plots, the Midilli model yielded an accurate prediction for the drying process of germinated rice under the tested settings. The suitable selection of models was evaluated based on coefficient of determination (R^2) and root mean square error (*RMSE*) values and the most accurate model was selected based on the highest R^2 and the lowest *RMSE*. Tab. 2 shows R^2 and *RMSE* values for all the six drying models tested. It was found that the Midilli model showed the best fit to the experimental data of two rice varieties with the highest R^2 values (between 0.9972 and 0.9995) and the lowest *RMSE* values (in the range of 0.0043–0.0080) among the models tested.

Effective moisture diffusivity

Tab. 3 shows D_{eff} values of the parboiled germinated paddy sample. At drying temperatures of 60–90 °C, parboiled germinated paddy had effective moisture diffusivity ranging from 0.82×10^{-10} $m^2 \cdot s^{-1}$ to 2.06×10^{-10} $m^2 \cdot s^{-1}$ for Sang Yod rice variety and ranging from 2.10×10^{-11} $m^2 \cdot s^{-1}$ to 6.65×10^{-11} $m^2 \cdot s^{-1}$ for Chaing Phatthelung rice variety. The diffusivity values increased with an increase in the drying temperature, length, and width of parboiled germinated paddy due to an increase in the contact surface area. D_{eff} values in this study were close to the values ranging from 3.87×10^{-10} $m^2 \cdot s^{-1}$ to 9.85×10^{-10} $m^2 \cdot s^{-1}$ reported for the fluidized bed drying of Chai Nat 1 brown rice at 90–150 °C [23] and ranging from 4.78×10^{-11} $m^2 \cdot s^{-1}$ to 1.36×10^{-11} $m^2 \cdot s^{-1}$ for fluidization bed drying of rough rice at 50–70 °C [24]. The differences between the results of D_{eff} values could be due to the shape, initial moisture content,and composition structure of the material, as well as the drying equipment, drying temperature and drying conditions [25]. Thus, impingement drying at 90 °C of the two germinated rice varieties in this work yielded the highest effective moisture diffusivity values.

Total proanthocyanidin content

The colour of brown rice occurs as a result of accumulation of three pigments including anthocyanins, flavonoids and proanthocyanins [26]. The rice samples in this study are Chaing Phatthalung and Sang Yod rice, which are varieties with a white membrane and red-brown membrane, re-

Tab. 3. Effective moisture diffusivity of parboiled germinated paddy at drying the kernels.

Rice varieties	T [°C]	D_{eff} [$m^2 \cdot s^{-1}$]	E_a [$kJ \cdot mol^{-1}$]	D_0 [$m^2 \cdot s^{-1}$]
Sang Yod	60	0.82×10^{-10}	31.23	6.39×10^{-6}
	70	1.12×10^{-10}		
	80	1.52×10^{-10}		
	90	2.06×10^{-10}		
Chaing Phatthalung	60	2.10×10^{-11}	25.52	3.19×10^{-7}
	70	3.08×10^{-11}		
	80	5.25×10^{-11}		
	90	6.65×10^{-11}		

T – temperature, D_{eff} – effective moisture diffusivity, E_a – activation energy, D_0 – pre-exponential factor of the Arrhenius equation.

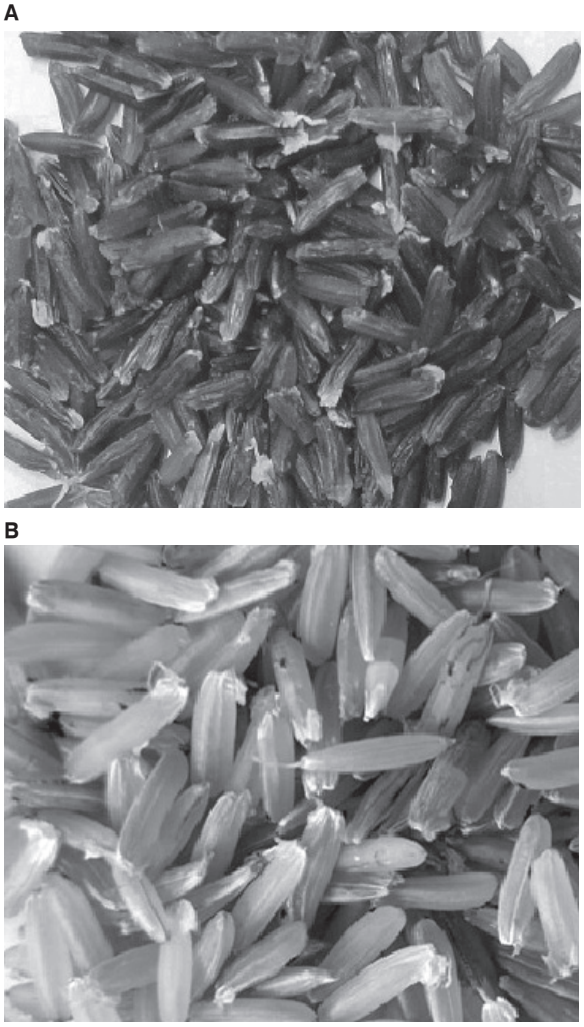

Fig. 3. Photographs showing the colour of germinated brown rice.

A – Sang Yod rice variety, B – Chaing Phatthalung rice variety.

Tab. 4. Effects of germination and drying temperature on bioactive compounds in samples.

Condition	*TPC* [g·kg^{-1}]		*TFC* [g·kg^{-1}]		*TPAC* [g·kg^{-1}]		GABA [g·kg^{-1}]	
	SY	CP	SY	CP	SY	CP	SY	CP
BR	109.24 ± 1.56^{b}	27.67 ± 1.89^{e}	44.95 ± 1.19^{b}	25.94 ± 0.21^{d}	65.30 ± 0.76^{b}	nd	0.03 ± 0.25^{c}	0.03 ± 0.35^{c}
GP	211.39 ± 0.34^{a}	93.75 ± 0.34^{a}	67.67 ± 1.34^{a}	42.98 ± 0.93^{a}	103.63 ± 1.67^{a}	nd	0.41 ± 0.95^{a}	0.34 ± 0.87^{a}
PGP60	71.59 ± 2.12^{cd}	60.41 ± 1.18^{bc}	31.12 ± 0.43^{cd}	34.46 ± 0.57^{bc}	27.80 ± 1.26^{d}	nd	0.34 ± 0.75^{ab}	0.28 ± 0.43^{b}
PGP70	71.00 ± 0.59^{cd}	57.47 ± 0.59^{cd}	30.26 ± 0.98^{cd}	34.33 ± 0.98^{bc}	27.13 ± 1.53^{d}	nd	0.33 ± 0.66^{ab}	0.28 ± 0.50^{b}
PGP80	69.82 ± 0.34^{cd}	55.12 ± 0.59^{cd}	30.26 ± 0.37^{cd}	33.96 ± 0.37^{bc}	26.47 ± 1.89^{d}	nd	0.33 ± 1.32^{ab}	0.27 ± 0.25^{b}
PGP90	69.63 ± 2.07^{cd}	54.14 ± 0.90^{cd}	30.14 ± 0.93^{cd}	33.84 ± 0.57^{bc}	25.80 ± 2.50^{e}	nd	0.33 ± 1.09^{ab}	0.27 ± 0.43^{b}

Means within columns followed by different superscript letters are significantly different at $p < 0.05$.
BR – brown rice, GP – germinated paddy dried in shade, PGP60, PGP70, PGP80, PGP90 – parboiled germinated paddy dried by hot air impingement drying at 60 °C, 70 °C, 80 °C and 90 °C, respectively, SY – Sang Yod rice variety, CP – Chaing Phatthalung rice variety, *TPC* – total phenolics content (expressed as grams of gallic acid equivalents per kilogram of sample), *TFC* – total flavonoids content (expressed as grams of catechin equivalents per kilogram of sample), *TPAC* – total proanthocyanidins content (expressed as grams of catechin equivalent per kilogram of dry rice flour), GABA – γ-aminobutyric acid, nd – less than detection limit.

spectively, so proanthocyanins were analysed. In addition, only the rice grain kernel with the purple and black membrane accumulates a large amount of anthocyanins. Proanthocyanins are phenolic compounds with antioxidant properties [26]. The analysis showed that brown rice of Sang Yod variety contained 65.30 ± 1.32 g·kg^{-1} proanthocyanins (Tab. 4). This is because the Sang Yod variety contains a red-brown membrane and due to this colour (Fig. 3), proanthocyanidin is accumulated. The proanthocyanidin was not found in the Chaing Phatthalung variety rice because the grains comprise non-pigmented rice. This result is consistent with the research of Huang and Lai [26]. The experimental results of drying germinated Sang Yod variety rice using the impingement hot air technique showed that the amount of proanthocyanidins was significantly reduced when compared with brown rice and germinated paddy. This was because proanthocyanins are water-soluble pigment that is unstable and easily decomposed by heat [19].

Total phenolics content and total flavonoids content

The *TPC* and *TFC* values of brown rice of Sang Yod variety were 109.24 ± 1.87 g·kg^{-1} and 44.95 ± 1.18 g·kg^{-1}, respectively, while the *TPC* and *TFC* values of brown rice of Chaing Phatthalung variety were 27.67 ± 1.89 g·kg^{-1} and 25.94 ± 0.21 g·kg^{-1}, respectively.

The effects of germination and temperature on *TPC* and *TFC* for various conditions are shown in Tab. 4. The percentage changes of TPC and TFC of dried products obtained from various conditions compared to brown rice samples were calculated to illustrate the changes as shown in Fig. 4. *TPC* and *TFC* in germinated paddy samples were the highest of both rice varieties. These results were similar to those reported by Kaur et al. [27]. This might be attributed to the fact that during the germination process of paddy, the carbohydrase enzyme hydrolyses the starch to release the bound phenolic compounds increasing the total phenolic content [27]. In particular, glucosidase enzymes were active in biochemical processes within rice kernels catalysing formation of phenolic compounds and flavonoids [27]. Therefore, the germination process led to an increase in phenolics and flavonoids content. Comparing the two rice varieties based on the obtained results, *TPC* and *TFC* of Sang Yod variety were higher than those of Chaing Phatthalung variety. Shao et al. [28] reported that the non-pigmented rice had lower *TPC* (0.008–0.472 g·kg^{-1}) than red and black-pigmented grains (0.066–0.626 g·kg^{-1}), as well as *TFC* of non-pigmented rice and red and black rice grains

ranged 0.63–1.14 g·kg^{-1} and 1.62–4.15 g·kg^{-1}, respectively, with non-pigmented rice showing lower values. The possible reason why the Sang Yod variety of rice is *TPC* and *TFC* higher than Chaing Phatthalung variety rice might be due to its colour. The Sang Yod rice variety has a red-brown colour containing pigments and is also considered a good source of phenolic acids [27, 28].

When the germinated paddy is compared with parboiled germinated paddy, the results showed that the latter was *TPC* and *TFC* lower than germinated paddy. Since the steaming and drying process cause thermic decomposition of phenolics and flavonoids, this is consistent with the results of WALTER et al. [29]. Parboiled germinated paddy has a lower *TPC* and *TFC* after the drying process, the amount of phenolic and flavonoid compounds of Sang Yod variety decreases. The germinated Sang Yod rice contains many types of phenolic compounds but less than those in the germinated Chaing Phatthalung rice, which is a rice with a pericarp of red-brown colour. Germinated Sang Yod brown rice contains proanthocyanidins, which are soluble and unstable at heat treatment [19]. Therefore, when germinated rice goes through the steaming and drying process, it leads to a decrease in the quantity of proanthocyanidins and a decrease in *TPC* and *TFC*. When considering parboiled germinated paddy at various drying temperatures, no significant difference was found in *TPC* and *TFC*. The use of the impingement drying technique resulted in a shorter drying period, which might have led to the insignificant difference found in *TPC* and *TFC* [29, 30].

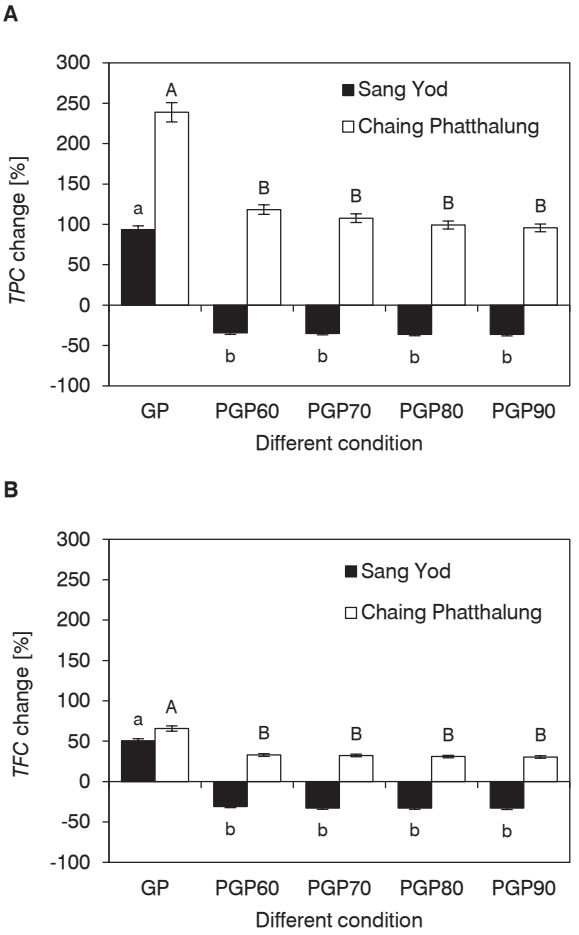

Fig. 4. Total phenolics content and total flavonoids content of rice dried at various conditions.

A – Total phenolics content, B – Total flavonoids content
Different lower case letters and different capital letters indicate a significant difference ($p < 0.05$) between different conditions at Sang Yod varieties rice and Chaing Phatthalung varieties rice, respectively.
TPC – total phenolics content, *TFC* – total flavonoids content, GP – germinated paddy dried in shade, PGP60, PGP70, PGP80, PGP90 – parboiled germinated paddy dried by hot air impingement drying at 60 °C, 70 °C, 80 °C and 90 °C, respectively.

Total antioxidant capacity

This section presents results of the analyses of the antioxidant capacity of both types of germinated rice by DPPH and FRAP assay methods. Both methods are widely known, easy to perform, convenient, stable and applicable to many samples. Percentage DPPH scavenging of Sang Yod and Chaing Phatthalung varieties were 85.4 % and 71.0 %, respectively, while the FRAP reducing power values of Sang Yod and Chaing Phatthalung varieties were 0.40 ± 2.99 g·kg^{-1} and 0.23 ± 2.24 g·kg^{-1}, respectively, as shown in Tab. 5. Percentage changes of DPPH scavenging and FRAP reducing power of both varieties of rice obtained at various conditions compared to brown rice were calculated to illustrate the degradation as shown in Fig. 5. The germinated paddy had higher antioxidant activity than brown rice and parboiled germinated paddy at various drying temperatures (60, 70, 80 and 90 °C). Since grain germination is a complex process in which enzymes hydrolyse starch to release the bound phenolic compounds, there is an increase in the total phenolics content [27]. The antioxidant capacity of parboiled germinated paddy was reduced because it was steamed and dried. This affected the decomposition of phenolic and flavonoid compounds resulting in an effect of the reduction of antioxidant properties [29, 30]. Fig. 5 also shows that the drying temperatures did not significantly affect ($p < 0.05$) the percentage change of DPPH scavenging and FRAP reducing power of the two rice varieties. These results agree with the data on the antioxidant capacity of germinated paddy samples

Tab. 5. Effects of germination and drying temperatures on antioxidant capacity of samples.

Sample	Antioxidant capacity			
	DPPH scavenging [%]		*FRAP* [g·kg^{-1}]	
	SY	CP	SY	CP
BR	85.36 ± 0.99 ^{b}	71.01 ± 2.98 ^{b}	0.40 ± 0.03 ^{b}	0.23 ± 0.01 ^{d}
GP	90.56 ± 1.14 ^{a}	78.28 ± 0.71 ^{a}	0.61 ± 0.01 ^{a}	0.42 ± 0.01 ^{a}
PGP60	81.21 ± 0.65 ^{cd}	74.31 ± 0.59 ^{ab}	0.32 ± 0.01 ^{cd}	0.28 ± 0.01 ^{c}
PGP70	80.45 ± 0.49 ^{cd}	74.13 ± 0.91 ^{ab}	0.31 ± 0.01 ^{cd}	0.28 ± 0.01 ^{c}
PGP80	79.98 ± 0.43 ^{cd}	73.94 ± 1.23 ^{ab}	0.31 ± 0.01 ^{cd}	0.28 ± 0.01 ^{c}
PGP90	79.32 ± 0.28 ^{cd}	73.37 ± 0.49 ^{ab}	0.30 ± 0.01 ^{d}	0.28 ± 0.01 ^{c}

Means within columns followed by different superscript letters are significantly different at $p < 0.05$.
BR – Brown rice, GP – germinated paddy dried in shade, PGP60, PGP70, PGP80, PGP90 – parboiled germinated paddy dried by hot air impingement drying at 60 °C, 70 °C, 80 °C and 90 °C, respectively, SY – Sang Yod rice variety, CP – Chaing Phatthalung rice variety, DPPH scavenging – DPPH radical-scavenging activity, *FRAP* – Ferric reducing antioxidant power (expressed as grams of Fe^{2+} equivalents per kilogram).

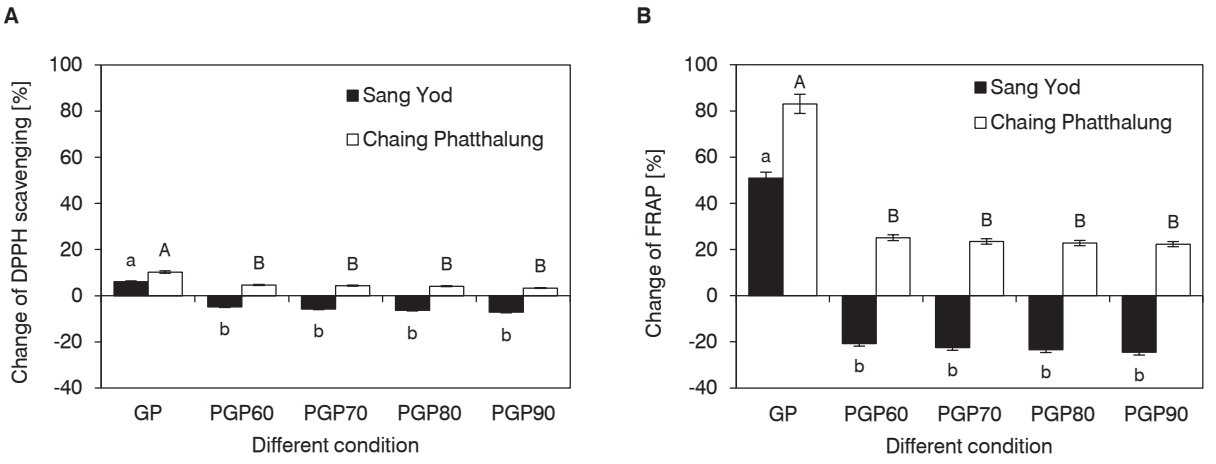

Fig. 5. Antioxidant activity of rice dried at various conditions.

A – DPPH radical-scavenging activity, B – Ferric reducing antioxidant power.
Different lower case letters and different capital letters indicate a significant difference ($p < 0.05$) among different conditions at Sang Yod rice varieties and Chaing Phatthalung rice varieties, respectively.
GP – germinated paddy dried in shade, PGP60, PGP70, PGP80, PGP90 – parboiled germinated paddy dried by hot air impingement drying at 60 °C, 70 °C, 80 °C and 90 °C, respectively.

by the DPPH radical-scavenging method. Finally, the result of the analyses of antioxidant capacity of both types of germinated paddy changed in the same direction as *TPC* and *TFC*.

γ-Aminobutyric acid content

The GABA content of brown rice of Sang Yod variety and Chaing Phatthalung variety were 0.03 ± 0.43 g·kg^{-1} and 0.03 ± 0.02 g·kg^{-1}, respectively. The amount of GABA in the two rice varieties occured as shown in Tab. 4. GABA contents of germinated paddy were the highest due to the fact that it was not thoroughly steamed and dried, which is consistent with the results of CHUNGCHAROEN et al. [23] on the GABA content of brown rice and germinated paddy at various drying temperatures. It was found that the GABA content of germinated paddy dried in shade was the highest. The increase in GABA content of germinated paddy is due to activation of glutamate decarboxylase (GAD) that catalyses decarboxylation of L–glutamic acid to carbon dioxide and GABA, which causes a decrease in glutamic acid [13, 27]. When considering parboiled germinated paddy, results showed that the amount of GABA decreased when compared to germinated paddy. This might have occured as a result of the phenomenon attributable to the inhibition of proteolytic enzymes and glutamate decarboxylase [31]. When considering the drying temperature with both varieties, result showed that the GABA content did not significantly differ ($p > 0.05$). Results

on the GABA content of the two varieties showed that Sang Yod variety contained more GABA than Chaing Phatthalung variety due to different initial GABA contents of brown rice, resulting in different values also after germination [32].

CONCLUSIONS

Impingement drying is a feasible rapid drying method for reducing hight moisture content of parboiled germinated paddy to ensure longer shelf life and to improve the microbiological safety of the product. In addition, the hot air impingement drying does not affect the grain integrity but also increases the head rice yield. Because the drying process causes partial gelatinization resulting in starch molecules being merged among themselves. The suitable drying temperature of parboiled germinated paddy using impingement drying was previously found to be 90 °C at air velocity 16 $m \cdot s^{-1}$ at saving the energy [33] and not affecting biologically active compounds. Importantly, this drying technique takes a short time and is able to reduce the moisture content from 53 ± 2 % DB down to 22 ± 3 % DB in 16–19 min. The Midilli model predicts the drying process of dried germinated rice more accurately than other models. The dried at higher temperatures led to increase in effective moisture diffusivity. The bioactive compounds and GABA content increased after the germination process. However, the steaming and drying process after germination led to a decrease in the bioactive compounds, antioxidant activities and GABA content. At using impingement drying technique at various temperatures, there was no significant difference in the bioactive compounds and GABA content in parboiled germinated paddy thanks to the short drying times.

Acknowledgements

The authors thank the Department of Chemical Engineering, Faculty of Engineering and Department of Physics, Faculty of Science Prince of Songkla University (Songkhla, Thailand) Hatyai campus for their experiment setting up supports, the Energy Policy and Planning Office (EPPO), Ministry of Energy (Bangkok, Thailand) No. 040/2560: PSU graduate grant and Interdisciplinary Graduate School of Energy System (IGS–Energy, Songkhla, Thailand) for their financial support.

REFERENCES

1. Cho, D. H. – Lim, S. T.: Germinated brown rice and its bio-functional compounds. Food Chemistry, *196*, 2016, pp. 259–271. DOI: 10.1016/j.foodchem.2015.09.025.
2. Hepsomali, P. – Groeger, J. A. – Nishihira, J. – Scholey, A.: Effects of oral gamma–aminobutyric acid (GABA) administration on stress and sleep in humans: A aystematic review. Frontiers in Neuroscience, *14*, 2020, article 923. DOI: 10.3389/fnins.2020.00923.
3. Suherman, S. – Hadiyanto, H. – Susanto, E. E. – Utami, I. A. P. – Ningrum, T.: Hybrid solar dryer for sugar–palm vermicelli drying. Journal of Food Process Engineering, *43*, 2020, e13471. DOI: 10.1111/jfpe.13471.
4. Menon, A. – Stojceska, V. – Tassou, S. A.: A systematic review on the recent advances of the energy efficiency improvements in non–conventional food drying technologies. Trends in Food Science and Technology, *100*, 2020, pp. 67–76. DOI: 10.1016/j.tifs.2020.03.014.
5. Deng, L. Z. – Mujumdar, A. S. – Yang, W. X. – Zhang, Q. – Zheng, Z. A. – Wu, M. – Xiao, H. W.: Hot air impingement drying kinetics and quality attributes of orange peel. Journal of Food Processing and Preservation, *44*, 2020, e14294. DOI: 10.1111/jfpp.14294.
6. Wang, H. – Liu, Z. L. – Vidyarthi, S. K. – Wang, Q. H. – Gao, L. – Li, B. R. – Wei, Q. – Liu, Y. H. – Xiao, H. W.: Effects of different drying methods on drying kinetics, physicochemical properties, microstructure, and energy consumption of potato (*Solanum tuberosum* L.) cubes. Drying Technology, *39*, 2021, pp. 418–431. DOI: 10.1080/07373937.2020.1818254.
7. Qiu, G. – Wang, D. – Song, X. – Deng, Y. – Zhao, Y.: Degradation kinetics and antioxidant capacity of anthocyanins in air–impingement jet dried purple potato slices. Food Research International, *105*, 2018, pp. 121–128. DOI: 10.1016/j.foodres.2017.10.050.
8. Brys, A. – Kaleta, A. – Górnicki, K. – Glowacki, S. – Tulej, W. – Brys, J. – Wichowski, P.: Some aspects of the modelling of thin-layer drying of sawdust. Energies, *14*, 2021, article 726. DOI: 10.3390/en14030726.
9. Moradi, M. – Fallahi, M. A. – Khaneghah, A. M.: Kinetics and mathematical modeling of thin layer drying of mint leaves by a hot water recirculating solar dryer. Journal of Food Process Engineering, *43*, 2019, e13181. DOI: 10.1111/jfpe.13181.
10. Forouzanfar, A. – Hojjati, M. – Noshad, M. – Szumny, A. J.: Influence of UV–B pretreatments on kinetics of convective hot air drying and physical parameters of mushrooms (Agaricus bisporus). Agriculture, *10*, 2020, article 371. DOI: 10.3390/agriculture10090371.
11. Nasri, F.: Solar thermal drying performance analysis of banana and peach in the region of Gafsa (Tunisia). Case Studies in Thermal Engineering, *22*, 2020, article 100771. DOI: 10.1016/j.csite.2020.100771.
12. Thuwapanichayanan, R. – Kumklam, P. – Soponronnarit, S. – Prachayawarakorn, S.: Mathematical model and energy utilization evaluation of a coaxial impinging stream drying system for parboiled paddy.

Drying Technology, *40*, 2022, pp. 157–174. DOI: 10.1080/07373937.2020.1775640.
13. Jirapa, K. – Jarae, Y. – Phanee, R. – Jirasak, K.: Changes of bioactive components in germinated paddy rice (*Oryza sativa* L.). International Food Research Journal, *23*, 2016, pp. 229–236. ISSN: 1985–4668. <http://www.ifrj.upm.edu.my/23%20(01)%202016/(34).pdf>
14. Horwitz, W. – Latimer, G. (Ed.): Official methods of analysis of AOAC International. 18th edition. Gaithersburg : AOAC International, 2005. ISBN: 0935584773.
15. Srisang, N. – Prachayawarakorn, S. – Varanyanond, W. – Soponronnarit, S.: Germinated brown rice drying by hot air fluidization technique. Drying Technology, *29*, 2010, pp. 55–63. DOI: 10.1080/07373937.2010.482691.
16. Xing–jun, L. – Xin, W. – Yang, L. – Ping, J. – Hui, L.: Changes in moisture effective diffusivity and glass transition temperature of paddy during drying. Computers and Electronics in Agriculture, *128*, 2016, pp. 112–119. DOI: 10.1016/j.compag.2016.08.025.
17. Deng, L. Z. – Yang, X. H. – Mujumdar, A. S. – Zhao, J. H. – Wang, D. – Zhang, Q. – Wang, J. – Gao, Z. J. – Xiao, H. W.: Red pepper (*Capsicum annuum* L.) drying: Effects of different drying methods on drying kinetics, physicochemical properties, antioxidant capacity, and microstructure. Drying Technology, *36*, 2018, pp. 893–907. DOI: 10.1080/07373937.2017.1361439.
18. Thammapat, P. – Meeso, N. – Siriamornpun, S.: Effects of NaCl and soaking temperature on the phenolic content, α–tocopherol, γ–oryzanol and fatty acids of glutinous rice. Food Chemistry, *175*, 2015, pp. 218–224. DOI: 10.1016/j.foodchem.2014.11.146.
19. Hu, Z. – Tang, X. – Liu, J. – Zhu, Z. – Shao, Y.: Effect of parboiling on phytochemical content, antioxidant activity and physicochemical properties of germinated red rice. Food Chemistry, *214*, 2017, pp. 258–292. DOI: 10.1016/j.foodchem.2016.07.097.
20. Matić, P. – Sabljić, M. – Jakobek, L.: Validation of spectrophotometric methods for the determination of total polyphenol and total flavonoid content. Journal of AOAC International, *100*, 2017, pp. 1795–1803. DOI: 10.5740/jaoacint.17-0066.
21. Benzie, I. F. F. – Strain, J. J.: The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. Analytical Biochemistry, *239*, 1996, pp. 70–76. DOI: 10.1006/abio.1996.0292.
22. Khantarate, S. – Theanjumpol, P. – Kriyyigamas, N. – Suriyong, S.: Effect of heat treatment on starch granule structure and nutrient content of germinated purple rice. Food Science and Technology, Epub 8 March 2021. DOI: 10.1590/fst.63820.
23. Chungcharoen, T. – Prachayawarakorn, S. – Tungtrakul, P. – Soponronnarit, S.: Effects of germination time and drying temperature on drying characteristics and quality of germinated paddy. Food and Bioproducts Processing, *94*, 2015, pp. 707–716. DOI: 10.1016/j.fbp.2014.09.013.
24. Khanali, M. – Banisharif, A. – Rafiee, S.: Modeling of moisture diffusivity, activation energy and energy consumption in fluidized bed drying of rough rice. Heat and Mass Transfer, *52*, 2016, pp. 2541–2549. DOI: 10.1007/s00231-016-1763-z.
25. Doymaz, I.: Drying kinetics, rehydration and colour characteristics of convective hot-air drying of carrot slices. Heat and Mass Transfer, *53*, 2017, pp. 25–35. DOI: 10.1007/s00231-016-1791-8.
26. Huang, Y. P. – Lai, H. M.: Bioactive compounds and antioxidative activity of colored rice bran. Journal of Food and Drug Analysis, *24*, 2016, pp. 564–574. DOI: 10.1016/j.jfda.2016.01.004.
27. Kaur, M. – Asthir, N. – Mahajan, G.: Variation in antioxidants, bioactive compounds and antioxidant capacity in germinated and ungerminated grains of ten rice cultivars. Rice Science, *24*, 2017, pp. 349–359. DOI: 10.1016/j.rsci.2017.08.002.
28. Shao, Y. – Hu, Z. – Yu, Y. – Mou, R. – Zhu, Z. – Beta, T.: Phenolic acids, anthocyanins, proanthocyanidins, antioxidant activity, minerals and their correlations in non–pigmented, red, and black rice. Food chemistry, *239*, 2018, pp. 733–741. DOI: 10.1016/j.foodchem.2017.07.009.
29. Walter, M. – Marchesan, E. – Massoni, P. F. S. – Silva, L. P. – Sartori, G. M. S. – Ferreira, R. B.: Antioxidant properties of rice grains with light brown, red and black pericarp colors and the effect of processing. Food Research International, *50*, 2013, pp. 698–703. DOI: 10.1016/j.foodres.2011.09.002.
30. Yilmaz, M. S. – Sakiyan, O. – Mazi, I. B. – Mazi, B. G.: Phenolic content and some physical properties of dried broccoli as affected by drying method. Food Science and Technology International, *25*, 2019, pp. 76–88. DOI: 10.1177/1082013218797527.
31. Watanabe, M. – Maeda, T. – Tsukahara, K. – Kayahara, H. – Morita, N.: Application of pregerminated brown rice for breadmaking. Cereal Chemistry Journal, *81*, 2004, pp. 450–455. DOI: 10.1094/CCHEM.2004.81.4.450.
32. Roohinejad, S. – Omidizadeh, A. – Mirhosseini, H. – Saari, N. – Mustafa, S. – Hussin, A. S. M. – Hamid, A. – Manap, M. Y. A.: Effect of pre-germination time on amino acid profile and gamma amino butyric acid (GABA) contents in different varieties of malaysian brown rice. International Journal of Food Properties, *14*, 2011, pp. 1386–1399. DOI: 10.1080/10942911003687207.
33. Wanthong, S. – Tirawanichakul, Y. – Tirawanichakul, S.: Comparative study of impingement and fixed-bed drying: kinetics and quality aspects of pregerminated GI rice. In: 2011 IEEE Colloquium on Humanities, Science and Engineering Research. Penang : IEEE, 2011, pp. 196–201. ISBN: 978-1-4673-0019-3. DOI: 10.1109/CHUSER.2011.6163715.

Received 10 September 2021; 1st revised 10 December 2021; accepted 19 January 2022; published online 1 March 2022.