

The Influence of Ethanol and Vacuum on Okara Drying

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Abstract

Okara is a coproduct of processing soy milk and tofu. It is often discarded but has a great potential for use in the food industry due to its high content of fiber and protein. The aim of this study was to evaluate the drying of okara by natural convection and by vacuum drying (10 kPa). The tested temperatures were 80 and 100 °C. The samples were fresh, or their surface was pretreated with ethanol. The kinetics of drying were fitted with empirical models from the literature. The following three factors improved drying and reduced drying time, 1) the use of ethanol as pretreatment, 2) vacuum application and 3) temperature. Among these factors, a greater reduction in time was observed when ethanol was used, followed by temperature and vacuum, in this order. Page's model showed the best fitness ($r^2 > 0.98$, RMSE < 0.05 and MAE < 0.11).

Keywords

Drying kinetics, Page model, Ethanol, Biomass, Soy

Introduction

Soybean (*Glycine max* L) products include soy oil, concentrate, isolate protein and water-soluble products such as soy drink and tofu [1]. Okara is an insoluble coproduct obtained during water soluble processing. It is a high moisture and fibrous material with a residual protein portion [2]. Its composition also includes minerals, vitamins and isoflavones [3]. Although it has a high nutritional value, it is highly perishable due to its high-water activity [4]. Gupta et al. [3] reported that okara could be fermented, hence it is easier to digest. The authors also commented that the use of raw okara is deficient. In order to use raw okara or preserve it for further use, it is imperative to reduce its water activity.

Besides reducing water activity, drying also reduces the volume and weight of products, leading to lower costs of packaging, transport and storage [5]. Convective drying is the most common and easily utilized drying method [6-8]. It is considered a simultaneous heat and mass transfer process, wherein water is transferred by diffusion from the interior of the food to the air-food interface and by convection from the food-air interface [9]. However, convective drying requires a large period of time [10].

Vacuum drying is an alternative to conventional drying and it allows water removal under reduced pressure and lower temperature. The pressure gradient is responsible for the output of water vapor from the feed and simultaneously the liquid inlet to the porous structure, which favors mass transfer, thus increasing the drying rate [11]. The use of ethanol for pretreatment could also reduce the drying

time, thus indicating that ethanol enhances the evaporation process when compared to conventional methods [9, 12].

The objective of this work was to study the drying of okara by two different methods: 1) natural convective drying and 2) vacuum drying. In this study, the pretreatment with ethanol was also tested. The drying kinetics was mathematically fitted with models from the literature.

Material and Methods

Material

Okara was obtained from a soybean processing factory. To prevent any fermentation, the material was refrigerated at 10 ± 2 °C, prior to the experiments.

Sample preparation

Okara is a paste and for drying experiments, samples were placed in Petri plates (10 cm diameter and 2 cm height). The total volume of the plates was covered with a sample weight of 10.01 ± 0.04 g. The samples were divided into two groups: In one of them, the samples had ethanol 95% dropped on their surface in a ratio of 0.13 mL/cm² sample [9].

Drying

The samples were dried in an oven (Solab SL 104/40, Piracicaba, Brazil) at temperatures of 80 and 100 °C, until the final moisture content of 2 kg water/100 kg sample was obtained. According to table 1, the drying methods used were natural convection drying and vacuum drying (vacuum pressure of 10 kPa).

Table 1: Experimental conditions of drying of okara.

Code	Vacuum use	Ethanol pretreatment
C80	No	No
V80	Yes	No
C _E 80	No	Yes
V _E 80	Yes	Yes
C100	No	No
V100	Yes	No
C _E 100	No	Yes
V _E 100	Yes	Yes

Where 'C' corresponds to natural convective drying, V to vacuum drying. The sub index E means drying of pretreated samples with ethanol. The number after the letter corresponds to the temperature, in °C.

Drying kinetics

The drying kinetics was experimentally obtained by determining the moisture content of the removed samples at preset times over the period under consideration. The experiments were conducted in triplicate with the average values reported.

Using the models listed in table 2, the experimental drying kinetics was modeled mathematically.

The term M_t corresponds to a non-dimensional moisture

content and is defined as:

$$M_r = \frac{(M_t - M_e)}{(M_0 - M_e)} \quad \text{----- (9)}$$

Table 2: Mathematical models used for drying kinetics adjustments.

Model	Equation	Reference
Page	$M_r = e^{(-k t^n)}$	Page [13]
Henderson and Pabis	$M_r = a e^{(-k t)}$	Henderson, Pabis [14]
Logarithmic	$M_r = a e^{(-k t)} + c$	Doymaz [15]
Midilli- Kucuk	$M_r = a e^{(k t^n)} + b t$	Midilli, Kucuk, Yapar [16]
Newton	$M_r = e^{(-k t)}$	Callaghan, Menzies, Bailey [17]
Wang and Singh	$M_r = 1 + a t + b t^2$	Wang, Singh [18]
Approximation of diffusion	$M_r = a e^{(-k t)} + (1-a) e^{(-k b t)}$	Kassem [19]
Two-term exponential	$M_r = a \cdot e^{(-k t)} + (1-a) \cdot e^{(-k a t)}$	Henderson [20]

Where a,b,c, k e n are adjustment parameters.

Where M_t is the moisture content in each time, M_0 , the initial moisture content and M_e , the equilibrium moisture content.

To evaluate the adjustment of the models, we used the coefficient of determination (r^2) (Equation 10) and the root mean square error (RMSE) (Equation 11).

$$r^2 = \frac{\sum_{i=1}^N (MR_{pre,i} - MR_{exp,avg})}{\sum_{i=1}^N (MR_{exp,i} - MR_{exp,avg})} \quad \text{----- (10)}$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2 \right]^{1/2} \quad \text{----- (11)}$$

Where $MR_{exp,i}$ and $MR_{prev,i}$ are respectively the experimental and predicted values of moisture reason for observation i, N is the number of observations n, the number of parameters in the model.

Analysis

Moisture content

The moisture content was measured in a vacuum oven at 70 °C (method number 934.06) [21].

Water activity (aw)

Water activity was determined at 25 °C using a water

activity meter (AquaLab Decagon Devices Inc. Pullman, model CX-2T, Washington, USA).

Results and Discussion

Experimental drying

Fresh samples of okara presented a moisture content of 82.0 ± 2.0 kg water/100 kg wet sample and a_w of 0.996 ± 0.003 . The high moisture content and water activity, as well as the chemical composition of food can be propitious to high rates of degradation, causing the loss of quality, according to Taseri et al. [22]. Dried samples of okara with a moisture content of 2 kg water/100 kg sample showed a_w of 0.435 ± 0.028 . The fresh values were in accordance with the literature [23]. Figure 1 presents the drying kinetics of okara for different

observed by [5, 10] during the drying process of pineapple and banana, respectively. The use of reduced pressures in vacuum drying improves the drying time (C80 and V80). The use of vacuum results in a decrease in the boiling point of water, leading to a higher temperature inside the dried particles than on the surface and this stimulates an increase in partial pressure that drives the evaporated water to the outside layer [25, 26]. The use of vacuum at 100 °C produced no significant results at 80 °C, but there was good water removal and decreased time of drying due to the high temperature. However, the use of high temperature for food drying has not been recommended because of the loss of heat-sensitive nutrients [27]. This is clearly evidenced during the drying of coffee beans using various drying methods in which higher temperatures with the methods resulted in greater degradation in product quality [28]. Therefore, the use of vacuum is important for decreasing temperature and drying time, leading to lower changes in the dried product, as indicated by Mendonca et al. [29] in the drying of pequi. Finally, the samples pretreated with ethanol presented shorter drying time and were more pronounced when using a combination of vacuum and ethanol treatment (V_E80 and V_E100) (table 3). According to Correa et al. [9], that evaluated the influence of ethanol on the convection drying of banana, the addition of ethanol increased water evaporation, thereby resulting in a shorter drying time. The same trend was observed in the drying of acerola residue [12]. Ethanol interacts with the moisture of the material and the resultant mixture has a vapor pressure higher than the product moisture recorded in the absence of ethanol, thus evaporation is facilitated [30].

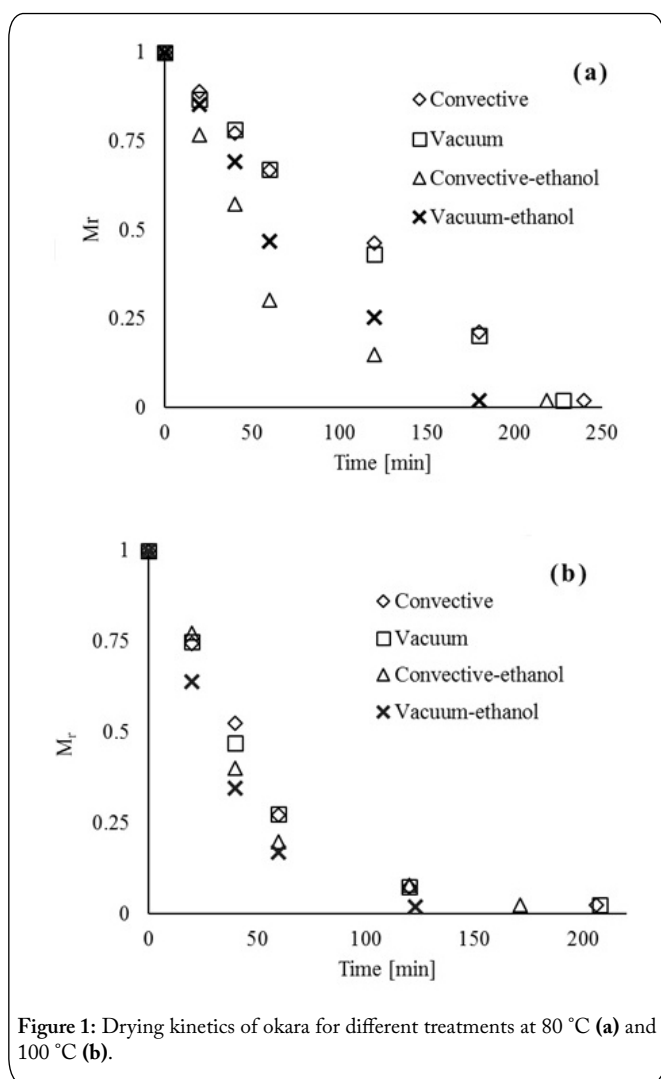


Figure 1: Drying kinetics of okara for different treatments at 80 °C (a) and 100 °C (b).

treatments, relating to the non-dimensional moisture content (M_r) with time and table 2 presents the drying time for each tested drying condition. The increase in temperature, the use of vacuum and the use of ethanol decreased drying time (C80 and C100; C_E80 and C_E100 ; V80 and V100; V_E80 and V_E100). The increase in air temperature resulted in larger driving forces for heat transfer and water evaporation [24]. This effect was

Table 3: Drying time of okara at different drying conditions.

Experiment code	Drying time [h]
C80	4.00 ± 0.20
V80	3.80 ± 0.35
C_E80	3.64 ± 0.32
V_E80	3.00 ± 0.20
C100	3.44 ± 0.29
V100	3.44 ± 0.40
C_E100	2.85 ± 0.41
V_E100	2.05 ± 0.05

Where 'C' corresponds to natural convective drying, V to vacuum drying. The sub index E means drying of pretreated samples with ethanol. The number after the letter corresponds to the temperature, in °C.

Modelling of drying kinetics

Table 4 presents the adjustment parameters of the tested models to experimental data, the coefficients of determination (r^2), root mean square error (RMSE) and mean absolute error (MAE).

When analyzing the coefficients of determination (r^2), Page's model presented values above 98% for both studied

temperatures. Page’s model was recommended by Madamba et al. [31] due to its agreement in the representation of drying. Moreover, Page’s model showed the smallest mean square error values and mean absolute error compared to the other

Table 4: Parameters of adjustment for different kinetics drying models.

Model	Experiment Code	Coefficients	MEA (10 ¹)	RME (10 ²)	r ²
Page	C80	$k = 9.00 \times 10^{-6}$; $n = 1.30$	6.07	4.31	0.98
	V80	$k = 1.02 \times 10^{-5}$; $n = 1.29$	6.50	4.17	0.98
	C _E 80	$k = 2.82 \times 10^{-4}$; $n = 9.94 \times 10^{-4}$	1.53	4.19	0.98
	V _E 80	$k = 6.75 \times 10^{-5}$; $n = 1.12$	7.40	4.39	0.98
	C100	$k = 3.77 \times 10^{-4}$; $n = 9.73 \times 10^{-1}$	1.69	4.30	0.98
	V100	$k = 2.77 \times 10^{-4}$; $n = 1.01$	1.19	5.91	0.99
	C _E 100	$k = 4.12 \times 10^{-6}$; $n = 1.57$	3.31	3.38	0.99
	V _E 100	$k = 3.54 \times 10^{-4}$; $n = 1.02$	2.00	2.53	0.99
Henderson and Pabis	C80	$k = 1.42 \times 10^{-4}$; $a = 1.05$	8.95	6.08	0.96
	V80	$k = 1.45 \times 10^{-4}$; $a = 1.04$	9.47	6.12	0.96
	C _E 80	$k = 2.85 \times 10^{-4}$; $a = 1.03$	1.23	4.04	0.98
	V _E 80	$k = 2.12 \times 10^{-4}$; $a = 1.05$	7.75	5.20	0.97
	C100	$k = 3.23 \times 10^{-4}$; $a = 1.03$	1.57	3.80	0.98
	V100	$k = 3.34 \times 10^{-4}$; $a = 1.03$	1.38	3.17	0.99
	C _E 100	$k = 3.75 \times 10^{-4}$; $a = 1.04$	1.33	5.64	0.97
	V _E 100	$k = 4.50 \times 10^{-4}$; $a = 1.02$	2.23	2.76	0.99
Logarithmic	C80	$k = 1.41 \times 10^{-4}$; $a = 1.08$; $c = -1.46 \times 10^{-2}$	8.27	6.00	0.96
	V80	$k = 3.72 \times 10^{-5}$; $a = 2.39$; $c = -1.41$	0.80	1.09	0.99
	C _E 80	$k = 2.83 \times 10^{-4}$; $a = 1.03$; $c = -5.11 \times 10^{-3}$	0.89	4.04	0.98
	V _E 80	$k = 1.88 \times 10^{-4}$; $a = 1.10$; $c = -3.71 \times 10^{-2}$	7.82	5.35	0.97
	C100	$k = 3.16 \times 10^{-4}$; $a = 1.04$; $c = -1.21 \times 10^{-2}$	2.13	3.71	0.98
	V100	$k = 3.30 \times 10^{-4}$; $a = 1.03$; $c = -6.86 \times 10^{-3}$	1.69	3.14	0.99
	C _E 100	$k = 3.63 \times 10^{-4}$; $a = 1.05$; $c = -1.44 \times 10^{-2}$	2.26	5.61	0.98
	V _E 100	$k = 4.07 \times 10^{-4}$; $a = 1.06$; $c = -4.76 \times 10^{-2}$	0.39	0.87	0.99
Midilli-Kucuk	C80	$k = 8.71 \times 10^{-4}$; $n = 6.431 \times 10^{-1}$; $a = 1.00$; $b = -4.50 \times 10^{-5}$	0.53	1.32	0.99
	V80	$k = 1.14 \times 10^{-3}$; $n = 5.89 \times 10^{-1}$; $a = 1.00$; $b = -5.20 \times 10^{-5}$	0.08	0.63	0.99
	C _E 80	$k = 5.46 \times 10^{-5}$; $n = 1.20$; $a = 1.00$; $b = 2.07 \times 10^{-6}$	2.14	3.45	0.98
	V _E 80	$k = 6.92 \times 10^{-4}$; $n = 7.96 \times 10^{-1}$; $a = 1.02$; $b = -2.90 \times 10^{-5}$	0.61	3.75	0.98
	C100	$k = 4.74 \times 10^{-4}$; $n = 9.56 \times 10^{-1}$; $a = 1.03$; $b = 2.17 \times 10^{-6}$	2.88	4.22	0.98
	V100	$k = 4.30 \times 10^{-4}$; $n = 9.65 \times 10^{-1}$; $a = 1.03$; $b = 8.98 \times 10^{-7}$	1.45	5.34	0.99
	C _E 100	$k = 2.85 \times 10^{-4}$; $n = 1.03$; $a = 1.04$; $b = 3.67 \times 10^{-7}$	1.17	5.66	0.97
	V _E 100	$k = 4.49 \times 10^{-2}$; $n = 1.90 \times 10^{-5}$; $a = 8.18 \times 10^{-1}$; $b = 1.44 \times 10^{-4}$	26.18	16.81	0.99
Approximation of diffusion	C80	$k = 1.53 \times 10^{-2}$; $a = -9.86 \times 10^{-2}$; $b = 9.54 \times 10^{-3}$	8.47	5.48	0.97
	V80	$k = 1.01 \times 10^{-1}$; $a = -1.01 \times 10^{-1}$; $b = 1.51 \times 10^{-3}$	8.74	5.56	0.97
	C _E 80	$k = 1.77 \times 10^{-2}$; $a = -1.33 \times 10^{-1}$; $b = 1.78 \times 10^{-2}$	1.04	3.33	0.99
	V _E 80	$k = 1.66 \times 10^{-2}$; $a = -5.58 \times 10^{-1}$; $b = 1.42 \times 10^{-2}$	6.23	3.90	0.98
	C100	$k = 9.73 \times 10^{-1}$; $a = -1.90 \times 10^{-1}$; $b = 3.87 \times 10^{-4}$	1.37	2.40	0.99
	V100	$k = 1.78 \times 10^{-2}$; $a = -2.10 \times 10^{-1}$; $b = 2.24 \times 10^{-2}$	1.38	0.93	0.99
	C _E 100	$k = 2.95 \times 10^{-1}$; $a = -4.53 \times 10^{-1}$; $b = 1.79 \times 10^{-3}$	2.39	2.20	0.99
	V _E 100	$k = 2.33 \times 10^{-2}$; $a = -2.24 \times 10^{-1}$; $b = 2.30 \times 10^{-2}$	0.46	0.53	0.99

Two-term exponential	C80	$k = 6.78 \times 10^{-2}$; $a = 1.90 \times 10^{-3}$	10.37	6.46	0.96
	V80	$k = 6.39 \times 10^{-2}$; $a = 2.09 \times 10^{-3}$	0.65	3.85	0.96
	C _E 80	$k = 2.61 \times 10^{-3}$; $a = 1.03 \times 10^{-1}$	1.51	4.18	0.98
	V _E 80	$k = 2.22 \times 10^{-3}$; $a = 8.75 \times 10^{-2}$	8.92	5.70	0.97
	C100	$k = 1.18 \times 10^1$; $a = 2.57 \times 10^{-3}$	1.54	4.03	0.98
	V100	$k = 9.80 \times 10^{-1}$; $a = 3.27 \times 10^{-4}$	1.36	3.41	0.99
	C _E 100	$k = 6.78 \times 10^{-2}$; $a = 1.90 \times 10^{-3}$	2.78	2.63	0.99
	V _E 100	$k = 1.38 \times 10^{-1}$; $a = 3.15 \times 10^{-3}$	2.59	2.93	0.99
Newton	C80	$k = 1.30 \times 10^{-4}$	0.21	6.42	0.96
	V80	$k = 1.38 \times 10^{-4}$	10.02	6.55	0.96
	C _E 80	$k = 2.63 \times 10^{-4}$	1.68	4.21	0.98
	V _E 80	$k = 1.96 \times 10^{-4}$	8.42	5.68	0.97
	C100	$k = 3.10 \times 10^{-4}$	1.54	4.00	0.98
	V100	$k = 3.22 \times 10^{-4}$	1.36	3.40	0.99
	C _E 100	$k = 3.58 \times 10^{-4}$	1.13	5.95	0.97
	V _E 100	$k = 4.40 \times 10^{-4}$	2.45	2.88	0.99
Wang and Singh	C80	$a = -8.98 \times 10^{-5}$; $b = 1.54 \times 10^{-9}$	0.72	1.78	0.99
	V80	$a = -9.21 \times 10^{-5}$; $b = 1.56 \times 10^{-9}$	1.08	1.43	0.99
	C _E 80	$a = -1.99 \times 10^{-4}$; $b = 9.64 \times 10^{-9}$	3.12	5.62	0.97
	V _E 80	$a = -1.49 \times 10^{-4}$; $b = 5.51 \times 10^{-9}$	1.66	3.49	0.98
	C100	$a = -2.23 \times 10^{-4}$; $b = 1.17 \times 10^{-8}$	3.25	4.32	0.98
	V100	$a = -2.27 \times 10^{-4}$; $b = 1.20 \times 10^{-8}$	5.86	6.57	0.98
	C _E 100	$a = -2.62 \times 10^{-4}$; $b = 1.66 \times 10^{-8}$	5.86	6.57	0.96
	V _E 100	$a = -3.31 \times 10^{-4}$; $b = 2.68 \times 10^{-8}$	0.39	0.87	0.99

Where 'C' corresponds to natural convective drying, V to vacuum drying. The subindex E means drying of pretreated samples with ethanol. The number after the letter corresponds to the temperature, in °C.

models. Page's model was also utilized for high values of r^2 up to 0.99 and low RMSE values below 0.02 in a fermented grape pomace drying [32].

At 100 °C, the models approximation diffusion, logarithmic and two-term exponential showed good fits with a minimum r^2 of 0.98 whereas Midilli et al.'s model showed a minimum r^2 values of 0.98 at 80 °C.

Conclusion

The drying time of a layer of okara (2 cm) was from 2 to 4 h. The processing time was decreased by pretreatment with ethanol, use of vacuum or by increasing the temperature.

According to the results, Page's model could be used to represent the drying of okara with suitable fitness.

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