Bulgarian Chemical Communications, Volume 57, Issue 3 (pp. 252-257) 2025 DOI: 10.34049/bcc.57.3.ZO-AK

Blanching and osmotic dehydration effects on lyophilized shrimp

Z. O. Ozyalcin, A. S. Kipcak*

Department of Chemical Engineering, Faculty of Chemical and Metallurgical Engineering, Yildiz Technical University, Istanbul, Türkiye

Accepted: September 10, 2025

Shrimp is the most widely consumed seafood worldwide, both as an ingredient in various dishes and as a tasty snack. Like many food products with high moisture content, shrimp are subjected to various drying processes. Among the drying systems, lyophilization is the method that preserves the nutritional values and the unique taste and texture of shrimp the most. In this study, the effects of blanching, blanching in saltwater and saltwater osmotic dehydration pretreatments on the lyophilization of shrimp were investigated. The effective moisture diffusion coefficient was calculated from the data obtained from the drying process and their compatibility with mathematical models was tested. Drying processes were completed between 240 - 360 min. It was observed that drying times could be reduced by blanching and osmotic dehydration pretreatments. In the compatibility with mathematical models, control and blanched samples fitted the Alibas model and osmotic dehydration samples fitted the Midilli & Kucuk model with R^2 values higher than 0.99999.

Keywords: Blanching; Freeze-drying; Osmotic dehydration; Saltwater; Shrimp

INTRODUCTION

Freeze-drying, also known as lyophilization, is a highly regarded method for dehydrating food, especially valuable for preserving delicate and high-quality products. This technique works by removing moisture through sublimation under low pressure, which helps maintain the food's original texture, nutrient content, and sensory characteristics—features often compromised in traditional drying processes [1, 2]. As it is a gentle process, freeze-drying is especially suitable for sensitive compounds commonly found in shrimp, such as omega-3 fatty acids, astaxanthin, and various bioactive peptides. Shrimp, like other seafood, is highly susceptible to spoilage due to its high water and protein content, as well as active endogenous enzymes. Without timely preservation, quality deteriorates rapidly. In this context, freeze-drying offers significant advantages: by drastically reducing water activity, it slows down microbial proliferation and enzymatic degradation—the main drivers of spoilage [1-5]. Research in recent years has confirmed that freeze-dried shrimp better retains its flavor, nutritional value, texture, and appearance compared to products processed through hot-air or vacuum drying [4, 6].

Despite its advantages, freeze-drying is known for being time- and energy-intensive, often requiring significant capital for equipment and operations [7]. To optimize the process and final product quality, various pre-treatment methods are employed, among which blanching and osmotic dehydration (OD) have proven effective. These techniques improve drying performance and product quality, offering benefits in terms of shelf life, nutrient retention, and sensory properties [8, 9].

Blanching, a short-term treatment involving exposure to hot water or steam, helps inactivating enzymes and altering the cell structure. This results in enhanced drying rates and better moisture diffusion during freeze-drying. Moreover, it aids in preserving color and reducing shrinkage. Products pre-treated with blanching generally show improved rehydration characteristics and reduced enzymatic browning, which contribute to superior texture and appearance [10, 11].

In contrast, osmotic dehydration involves placing food items in a concentrated solution, usually containing salt or sugar, to draw water out through osmosis. This not only pre-dehydrates the product but also helps preserve cell structure and nutritional value. OD-treated foods tend to retain better color and flavor while minimizing textural damage. For instance, studies on strawberries have shown that OD prior to freeze-drying enhances vitamin C content, antioxidant activity, and visual quality [8, 12, 13].

Mathematical modeling is another key area that supports the optimization of the freeze-drying

* To whom all correspondence should be sent:
E-mail: *skipcak@yildiz.edu.tr*

process. By applying heat and mass transfer models, researchers can predict drying kinetics and adjust parameters to minimize energy use while maximizing quality retention [14, 15]. Models typically describe the unsteady heat and mass transfer during freeze drying, involving coupled nonlinear partial differential equations to represent temperature and pressure profiles, and the position of the sublimation interface [16].

Various mathematical models are often used to study freeze-drying of seafoods. For example, squid, shrimp, mussels, and salmon have been investigated for their freeze-drying properties, effective moisture diffusivity, and quality parameters [14, 17]. The present research was conducted to fill the voids in the freeze-drying of shrimp utilizing blanching, blanching in saltwater, and osmotic dehydration pretreatments in saltwater. The effective moisture diffusion coefficient was determined using data acquired from the drying process, and its compatibility with ten established mathematical models was evaluated.

MATERIALS AND METHODS

Sample preparation

Frozen shrimp (sourced from Turkiye) were acquired from a local market and stored at a temperature of -18 ± 2 °C in a freezer (model 1050T; Arçelik, Eskişehir, Turkiye). Before the experiments, the shrimp were thawed at +4 ± 2 °C and subsequently allowed to equilibrate to room temperature in a desiccator. The shrimp samples were weighed using a AS 220.R2 digital balance (Radwag, Radom, Poland). The initial moisture content was assessed following the AOAC (2005) methodology [18], which involved drying the samples for a duration of 4 h at 105 °C in a KH-45 hot air oven (Kenton, Guangzhou, China).

Drying experiments

Shrimp samples were prepared with a weight of 5.0 ± 0.100 g across 9 sets of control and pretreatment conditions. For the blanching process, samples were submerged in beakers filled with 100 mL of deionized water at a temperature of 90°C for durations of 1 min (B–1 min) and 5 min (B–5 min). In the case of blanching using a 10% (w/v) salt solution, the samples were immersed for 1 min (B 10% – 1 min) and 5 min (B 10% – 5 min) in 100 mL of deionized water at 90 °C. For osmotic dehydration in salt solution at room temperature, the samples were placed in deionized aqueous solutions with 10% (w/v) salt and maintained for 5 min (OD 10% - 5 min), 10 min (OD 10% - 10 min) and with 20% (w/v) salt and maintained for 5 min (OD 20% - 5 min), 10 min (OD 20% - 10 min). Following the pretreatment procedures, any excess water was removed, and the samples were promptly transferred to a Labart LFD-10N freeze dryer (ART Laborteknik, Istanbul, Turkiye). Throughout the freeze-drying process, the vacuum within the drying chamber was released every 60 min, during which the samples were weighed and photographed within a time frame of less than 2 min. Subsequently, the samples were returned to the dryer, and the vacuum was reestablished. The drying process concluded, and the samples were vacuum-packed once their moisture content fell below 5% of their dry weight.

Mathematical modeling

The study of moisture diffusion during the drying process is based on Fick's second law which provides a mathematical basis for understanding how moisture travels through materials. This law is especially significant when drying processes are essential for maintaining product quality and stability. In the constant rate phase of drying, moisture is mainly extracted from the surface, while in the falling rate phase, internal diffusion takes precedence as moisture migrates from the interior to the surface [19].

The moisture content (M, kg water/kg dry matter) present in shrimp, along with its moisture ratio (MR, dimensionless), is described by Eqn. (1). In these equations, m_w denotes the quantity of water in the sample (kg), while m_d signifies the amount of dry matter (kg) [20].

$$M = \frac{m_w}{m_d} \tag{1}$$

In Equation (2), M_t indicates the moisture content at any specific time, M_0 refers to the initial moisture content, and M_e represents the moisture content at equilibrium. Given that the equilibrium moisture content is significantly lower than other moisture values, it has been disregarded in the calculations [21]:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{2}$$

The data collected from dried shrimp were analyzed utilizing the Statistica 8.0 software (StatSoft Tulsa, USA). Initially, the appropriateness of the model for all mathematical modeling approaches was assessed through regression parameters. One of the criteria employed to evaluate the fit of experimental data to the model equations is the coefficient of determination (R^2) value presented in Eqn. (3). An R^2 value approaching 1 signifies a strong alignment between the data and the model [22]:

$$R^2 \equiv 1 - \frac{\sum_{i=1}^{N}\left(MR_{exp,i}-MR_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{exp,i}-\left(\frac{1}{n}\right)\sum_{i=1}^{N}MR_{exp,i}\right)} \quad (3)$$

Additional evaluated criteria include the chi-square (χ^2), which represents the average of the squares of the drying data compared to the predicted data derived from the model equation, and the root mean square error (RMSE) which indicates the square root of the mean of the discrepancies between the drying data and the predicted values. The proximity of these values to 0, as defined in Eqns. (4) and (5), suggests a high degree of compatibility between the models and the drying data [23]:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i}-MR_{pre,i}\right)^2}{N-z} \quad (4)$$

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}\left(MR_{exp,i}-MR_{pre,i}\right)^2\right)^{\frac{1}{2}} \quad (5)$$

The terms MR_{exp} and MR_{pre}, as defined in Equations (3-5), denote the moisture ratio values derived from both experimental and model equations, respectively. The variable N signifies the total number of experiments conducted, while the variable z indicates the constant values utilized within the models.

Effective moisture diffusivity

During the drying process of food products, moisture is removed from the structure at either a constant or diminishing rate, revealing a complex mass transfer mechanism. Fick's second law of diffusion is commonly employed to ascertain the effective moisture diffusivity coefficient (D_{eff}) in food products (Eqn. 6). The value of D_{eff} is influenced by numerous factors, including the components present in the food structure, moisture content, drying temperature, and porosity of the food [24]:

$$\frac{\partial M}{\partial t} = \nabla\left[D_{eff}(\nabla M)\right] \quad (6)$$

The effective moisture diffusivity (D_{eff}) can be determined from the slope of the ln(MR) *versus* time plot (Eqn. 7):

$$\ln(MR) = \ln\left(\frac{6}{\pi^2}\right) - \left(\pi^2\frac{D_{eff}\times t}{R^2}\right) \quad (7)$$

Ten mathematical models, the formulations of which are presented in Table 1, were employed to assess the compatibility of the models commonly studied in drying processes.

RESULTS AND DISCUSSION

Table 2 presents the initial and final moisture contents, along with the drying durations, for shrimp samples subjected to various pretreatment methods prior to freeze-drying. The initial moisture content ranged from 77.47% to 86.42%, corresponding to an initial moisture load of 3.4382 to 6.3626 kg water / kg dry matter (DM). These variations reflect the influence of different pretreatment conditions on the water-holding capacity of the samples.

Table 1. Mathematical model equations [21, 24]

Model name	Model equation
Aghbaslo *et al.*	$MR = exp\ (-k_1t/(1 + k_2t))$
Alibas	$MR = a.exp\ ((-kt^n) + bt) + g$
Jena and Das	$MR = a.exp\ (-kt + b\sqrt{t}) + c$
Lewis	$MR = exp\ (-kt)$
Logarithmic	$MR = a.exp\ (-kt) + c$
Midilli & Kucuk	$MR = a.exp\ (-kt^n) + bt$
Page	$MR = exp\ (-kt^n)$
Parabolic	$MR = a + bt + ct^2$
Wang and Singh	$MR = 1+ at + b\ t^2$
Two-term Exponential	$MR = a.\ exp\ (-kt) + (1-a).\ exp\ (-kat)$

*a, b, c, g, are coefficients; n is the drying exponent unique to each equation; k, k_1, k_2, are drying coefficients specific to each equation; t indicates time (min).

The control group, which received no pretreatment, exhibited an initial moisture content of 86.02% and required 360 min of freeze-drying to reach a final moisture content of 0.053 kg W/kg DM. Similarly, B–5 min sample showed a comparable initial moisture level (86.42%) but achieved a significantly lower final moisture (0.0047 kg W/kg DM), suggesting enhanced drying efficiency. B–5 min reduced the initial moisture content to 82.22% and required 300 min of drying, resulting in a final moisture content of 0.1167 kg W/kg DM. Samples treated with 10% salt solution (B10%–1 min and B10%–5 min) displayed progressively lower initial moisture levels (84.21% and 77.47%, respectively), with the 5-min sample requiring only 240 min to dry, indicating a substantial acceleration in moisture removal.

In contrast, osmotic dehydration (OD) treatments demonstrated a different pattern. The OD 10% – 5 min and OD 10% – 10 min samples had moderate initial moisture levels (~82–83%) but resulted in higher final moisture contents (0.515 and 0.1181 kg W/kg DM, respectively), suggesting that osmotic pretreatment may hinder complete water removal, potentially due to solute uptake affecting water mobility. OD 20% treatments (5 and 10 min) led to higher initial moisture values (~84%) and required 300 and 240 min of drying, respectively, but still retained higher final moisture (0.29 and 0.1934 kg W/kg DM) compared to the control.

The temporal variation of moisture content and the relationship between moisture content and drying rate are presented in Figures 1 and 2. As depicted in Figure 2, it is evident that the pretreated samples transitioned into the falling rate period sooner, attributable to their elevated moisture content. Table 3 presents the compatibility results of best-fitted mathematical models with R^2 values over 0.9999.

Table 2. Drying data of shrimp

Sample	Initial moisture (%)	Initial moisture (kg W / kg DM)	Drying time (min)	Final moisture (kg W / kg DM)
Control	86.02	6.1507	360	0.0530
B – 1 min	86.42	6.3626	360	0.0047
B – 5 min	82.22	4.6255	300	0.1167
B 10% – 1 min	84.21	5.3317	360	0.0650
B 10% – 5 min	77.47	3.4382	240	0.0896
OD 10% – 5 min	83.05	4.9012	300	0.5150
OD 10% – 10 min	81.97	4.5471	300	0.1181
OD 20% – 5 min	84.86	5.6067	300	0.2900
OD 20% – 10 min	84.28	5.3613	240	0.1934

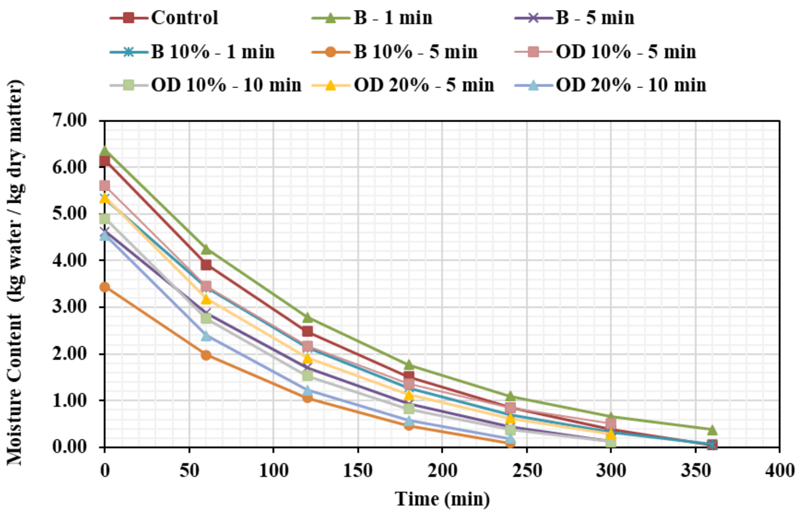

Figure 1. Moisture content *vs.* drying rate graph of freeze-drying shrimp

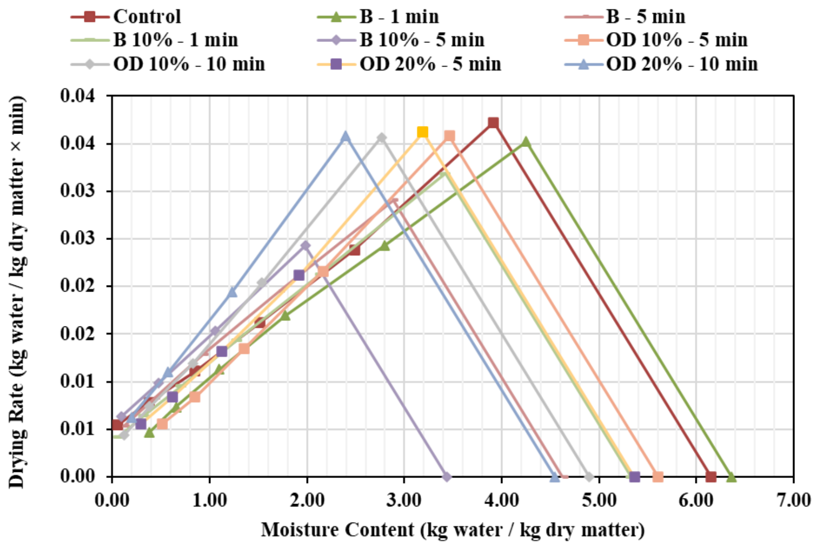

Figure 2. Drying rate *vs.* moisture content graph of freeze-drying shrimp

Table 3. Mathematical model constants and statistical parameters of freeze-dried shrimp

Sample	Model	R^2	χ^2	RMSE
Control	Alibas	0.99999998	0.0000001	0.000182
	Midilli & Kucuk	0.99999641	0.0000009	0.000626
	Verma *et al.*	0.99998960	0.0000040	0.001518
B - 1 min	Alibas	0.99999772	0.0000010	0.000479
	Aghbashlo *et al.*	0.99999234	0.0000011	0.000877
	Logarithmic	0.99993275	0.0000120	0.002599
B - 5 min	Alibas	0.99999945	0.0000002	0.000232
	Verma *et al.*	0.99999929	0.0000001	0.000263
	Midilli & Kucuk	0.99999391	0.0000014	0.000771
B %10 - 1 min	Alibas	0.99999975	0.0000001	0.000167
	Logarithmic	0.99999601	0.0000012	0.000697
	Midilli & Kucuk	0.99999359	0.0000016	0.000839
B %10 - 5 min	Alibas	0.99999991	0.0000001	0.000001
	Midilli & Kucuk	0.99999915	0.0000005	0.000321
	Logarithmic	0.99999601	0.0000012	0.000697
OD %10 - 5 min	Alibas	0.99999870	0.0000008	0.000356
	Midilli & Kucuk	0.99999663	0.0000010	0.000574
	Verma *et al.*	0.99998827	0.0000023	0.001072
OD %10 - 10 min	Alibas	0.99999629	0.0000025	0.000649
	Midilli & Kucuk	0.99999622	0.0000013	0.000655
	Verma *et al.*	0.99999162	0.0000019	0.000976
OD %20 - 5 min	Midilli & Kucuk	0.99999997	0.00000001	0.000018
	Aghbashlo *et al.*	0.99972728	0.0000433	0.005374
	Verma *et al.*	0.99927421	0.0001537	0.008767
OD %20 - 10 min	Midilli & Kucuk	0.99999951	0.0000003	0.000241
	Verma *et al.*	0.99999810	0.0000006	0.000476
	Logarithmic	0.99997934	0.0001115	0.001569

Among the tested models, the Alibas and the Midilli & Kucuk models consistently outperformed others across nearly all sample groups, achieving the highest coefficients of determination (R^2) and the lowest error metrics (χ^2 and RMSE). This consistency indicates that these models are highly effective at capturing the complex moisture dynamics during freeze-drying, regardless of whether the shrimp underwent boiling or osmotic dehydration.

Notably, the Midilli & Kucuk model showed exceptional performance in samples treated with ultrasound-assisted osmotic dehydration at higher concentrations and durations (e.g., OD %20 – 5 min), with near-perfect R^2 and minimal errors, suggesting that this model is particularly suited to capturing the enhanced moisture diffusion effects introduced by ultrasound treatment.

CONCLUSION

This study examined the freeze-drying properties of shrimp that had been blanched, blanched in salt water, osmotically dehydrated, and control samples. The drying durations were found between 240 - 360 min. Overall, blanching and blanching in salt water pretreatments enhanced moisture diffusivity and drying efficiency, while osmotic dehydration appeared less effective in reducing the final moisture content under the given conditions. When the compatibility of mathematical models with freeze-drying data was examined, the Alibas and the Midilli & Kucuk models yielded the best fit.

REFERENCES

1. D. Dziki, *Processes*, **8**, 1661 (2020).
2. S. Latif, M. Sohaib, S. Iqbal, M. H. Mushtaq, M. T. Sultan, *AIMS Agric. Food*, **10**, 247 (2025).
3. C. Aktar, G. N. Ural, A. H. M. Kaya, O. K. Topuz, *Acta Aliment.*, **53**, 464 (2024).
4. D. Y. Li, D. Y. Zhou, F. W. Yin, X. P. Dong, H. K. Xie, Z. Y. Liu, F. Shahidi, *J. Sci. Food Agric.*, **100**, 2544 (2020).
5. S. Mašić, I. Vujčić, *Nukleonika*, **66**, 4 (2021).
6. X. Xuan, L. Wen, Y. Cui, H. Shang, X. Lin, J. Ling, *Sci. Technol. Food Ind.*, **40**, 79 (2019).
7. T. Zhu, F. Jameel, P. Pibulchinda, V. Kshirsagar, A. Alexeenko, in *Principles and Practices of Lyophilization in Product Development and Manufacturing*, Springer, Cham, 2023, p. 405.
8. R. M. Putri, M. A. F. Falah, *IOP Conf. Ser.: Earth Environ. Sci.*, **1200**, 012030 (2023).
9. A. Ciurzyńska, A. Lenart, *Żywność Nauka Technol. Jakosć*, **20**, (2013).
10. F. Richter Reis, in: New Perspectives on Food Blanching, 2017, p. 123.
11. S. S. Ferreira, F. Monteiro, C. P. Passos, A. M. Silva, D. F. Wessel, M. A. Coimbra, S. M. Cardoso, *Food Res. Int.*, **132**, 109055 (2020).
12. B. D. S. Pinto, A. C. C. D. Melo, E. F. D. Costa Jr., A. O. S. D. Costa, *Ciênc. Rural*, **53**, e20200935 (2022).
13. S. Malakar, T. Manonmani, S. Deb, K. K. Dash, in Food Processing, CRC Press, 2021, p. 67.
14. Z. O. Ozyalcin, E. Güles, D. Uygunoz, F. Bozkurt, O. Sagdic, I. Doymaz, A. S. Kipcak, *TrJFAS*, **25**, 2 (2024).
15. S. Sevim, Z. O. Ozyalcin, A. S. Kipcak, *TrJFAS*, **23**, 12 (2023).
16. P. Levin, M. Buchholz, V. Meunier, U. Kessler, S. Palzer, S. Heinrich, *Processes*, **10**, 548 (2022).
17. E. Midik, Z. O. Ozyalcin, A. S. Kipcak, *J. Chem. Technol.*, **33**, 136 (2025).
18. AOAC, Official Method of Analy*sis*, 18th edn., Association of Officiating Analytical Chemists, Washington DC, 2005.
19. Z. O. Ozyalcin, A. S. Kipcak, *Bulg. Chem. Commun.*, **55**, 234 (2023).
20. Z. O. Ozyalcin, A. S. Kipcak, *TrJFAS*, **21**, 135 (2021).
21. A. Ersan, A. S. Kipcak, N. Tugrul, *J. Food Sci. Technol.*, **61**, 1 (2024).
22. S. Kipcak, O. Ismail, *J. Food Sci. Technol.*, **58**, 281 (2021).
23. Z. O. Ozyalcin, A. S. Kipcak, N. Tugrul, *J. Aquat. Food Prod.*, **32**, 384 (2023).
24. A. S. Kipcak, I. Doymaz, *Int. J. Fruit Sci.*, **20**, S1222 (2020).
25. Z. O. Ozyalcin, A. S. Kipcak, *J. Aquat. Food Prod.*, **31**, 187 (2022)