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SCIENTIFIC PAPER

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THE DRYING KINETICS AND CHARACTERISTICS OF SHRIMP DRIED BY CONVENTIONAL METHODS

Article Highlights

- Drying shrimp is very important in terms of increasing shelf life and not spoiling
- Increasing the drying temperature saves time by drying the shrimp in a shorter time
- The protein content of dried shrimp was higher than protein content of undried shrimp
- The heavy metal content of the dried shrimp was at acceptable levels for human health
- The rehydration ratio increased due to the increased drying temperature for both methods

Abstract

The main purpose of this study was to research the influence of different drying methods on the physical and qualitative properties of dried shrimps. Shrimps were dried with conventional methods at 60, 70 and 80 °C between 330 to 210 min and 190 to 110 min, in an oven and vacuum oven respectively. Drying time was shortened with the use of a vacuum pump. The drying kinetics of the shrimp were studied, and effective moisture diffusion and activation energy were calculated for both methods. The Alibas model and the Midilli and Kucuk model provided the best experimental data with a high coefficient of determination (R^2) for the oven and vacuum oven techniques, respectively. The final dried products were characterized by investigating the color characteristics, heavy metal content and by carrying out protein analyses. The rehydration ratio was also determined for the dehydrated shrimps. Drying conditions affected the color features so that shrimps dried in ovens and vacuum ovens showed an increase in brightness and yellowness values and a decrease in redness values. The concentration of As, Pb, Cd, Hg, Cu, Zn and Fe in the dried shrimp were within acceptable limits. The protein content of dried shrimp (~85%) is higher than that of undried shrimp (~20%).

Keywords: shrimp, drying kinetics, rehydration, protein content, color analysis, heavy metal.

Aquatic creatures like marine molluscs and insects have a high protein content and have been eaten for many years cooked or uncooked. Shrimps come from the family *Penaeidae* and are known as *Parapenaeus longirostris*. They are widely consumed in many countries of the world, especially in the Far East, with two thousand five hundred known species. Sixty-one species are found in the sea around Turkey and only seven of them are considered to be commercially viable. Shrimps are consumed a great deal in Turkey because the country is surrounded by the sea from three sides. Aquatic creatures can easily degrade due to microbiological activity; however, it can be reduced by decreasing their moisture content. There are many drying methods that can be found in published literature, including microwaves, hot air oven, vacuum-hot air oven, infrared drying, etc. The advantages of hot air drying are the equipment's simplicity, low cost, flexibility and easy control. However, low energy efficiency, long drying times and low thermal conductivity of foods are the disadvantages of hot air drying. The quality of the dried foods can be

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improved by decreasing the drying temperature or the drying period. Therefore, instead of the hot air oven, vacuum-hot air oven drying is preferred [1-3]. In recent years, modern drying methods have become areas of interest in the dehydration of agricultural products like fruits and vegetables. This is because these drying techniques cause fast water evaporation and result in high drying ratios, thus they reduce the drying time and consume less energy [4,5]. Drying is a complex process, including simultaneous heat and mass transfer for the removal of moisture from the wet food and air. Food product behavior during drying is determined from the drying kinetics analyses. Mathematical models that characterize the drying process are employed to optimize drying systems working conditions [6-7].

There are many researches on drying food products. However, these studies are based on drying vegetables and fruits. There are fewer studies on meat and aquatic products. Humanity has to consume food products to survive. Food products, and especially aquatic products, deteriorate quickly. Drying methods are used to prevent this deterioration and increase the shelf life of foods. Examples of drying studies with different meat products include the following: Traffano-Schiffo *et al.* [8] studied the drying of meat with infrared thermography, Jangsawang [9] studied drying different meat products with a cabinet dryer and Corona *et al.* [10] studied ultrasonic characterization of dried meat products. Cantalejo *et al.* [11] studied freeze drying of chicken meat, while Dinçer and Erbaş [12] studied drying kinetics of vacuum-dried beef slices. Akhtar and More [13] studied the convective drying process of chicken meat.

There are very few studies about drying marine products. Tsuruta and Hayashi [14] practised the warm-air drying for seafood. Tirawanichakul *et al.* [15] studied hot air convection drying of shrimp, Zhang *et al.* [16] studied different drying methods of fruits, vegetables and aquatic products and Komolafe *et al.* [17] studied convective fish drying. Bai and Sun [18] studied electrohydrodynamic drying technique for shrimps. Bellagha *et al.* [19] studied drying of sardines. Jain and Pathare [20] studied the drying kinetics of fish dried via sun. Kipcak [21] studied microwave drying and Kipcak *et al.* [22] studied the infrared drying of the mussel.

There are many researches on drying meat, chicken and some on aquatic products in public literature, but there are a few studies conducted on the drying of shrimps by conventional drying methods. In this study, shrimps were dried with conventional methods (oven and vacuum oven drying). The drying rate, moisture ratio and moisture content of the shrimps were calculated, regression analyses were carried out, effective moisture diffusivity, activation energies and rehydration rates were also estimated. The color of dried products is one of the most important criteria for product quality, so color analysis was performed, as well as a heavy metal and protein content analysis. The scope of this study was to find out the effects of oven and vacuum oven drying methods on drying characteristics, color changes, heavy metal content and protein content of dried shrimp.

EXPERIMENTAL

Sample preparation

Fresh shrimps, caught in Turkish seas, were provided from a local store in İstanbul in February 2019 and were stored in a freezer at a temperature of 4 °C. Shrimp products were stored in the freezer for two days before drying experiments. The shrimp were taken out of the freezer 12 h before the experiment and kept at room temperature. In the experimental stage, shrimps of similar size were selected to have a mean length of 3.5±0.1 cm. The moisture content of the shrimps was obtained to be 4.8824 kg of water/kg of dry matter by using the AOAC method initially [23].

Drying experiments

Drying experiments of products were performed in a Nuve EV 018 model oven, working at ~220 V, 50 Hz, 3.5 A and an 800 W power output. The temperature setting was in increments of 1 °C and able to rise up to 250 °C if needed. The drying area was 30 cm L×20 cm H×25 cm W and vacuum conditions were produced by a laboratory type vacuum pump (KNF N026 1.2 AN 18, Turkey). The vacuum pump operated at 220 V, 50 Hz and a current of 0.85 A. The drying process was performed at 60, 70 and 80 °C with the oven and vacuum oven. When the moisture content of the shrimps decreased to 0.35±0.143 kg of water/kg of dry matter (dry basis), the drying process was terminated. Dried shrimps were cooled in a desiccator at room temperature when the drying process was completed. Afterwards, dried samples were stored in bags which are made of low-density polyethylene (LDPE). This procedure was repeated at different temperatures.

Modelling and regression analyses

The moisture content (M), moisture ratio (MR) and drying rate (DR) of shrimps were estimated by using Eqs. (1), (2) and (3) [4,5,22]:

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

where m_w, m_d and M are the water content (g), dry matter content (g) and moisture content (kg of water/kg dry matter), respectively.

$$DR = \frac{M_{t+\mathrm{d}t} - M_t}{\mathrm{d}t} \tag{2}$$

where t is the drying time in minutes, $M_{t+\mathrm{d}t}$ is the moisture content at t+dt (kg water/kg dry matter), and DR is the drying rate (kg water/kg dry matter × min).

$$MR = \frac{M_t - M_e}{M_i - M_e} \tag{3}$$

where MR is the moisture ratio, M_t is the moisture content at the chosen time, M_e is the equilibrium value, and M_i is the initial value in kg water/kg dry matter. In the calculations, M_e is generally neglected due to its small number.

The drying curve data of each oven and vacuum oven method were fitted to 14 most widely used mathematical models: Aghbashlo *et al.*, Alibas, Henderson and Pabis, Jena and Das, Lewis, logarithmic, Midilli and Kucuk, Page, parabolic, Peleg, two-term exponential, Verma, and Wang and Weibull.

Regression analyses were practised *via* Statistica 8.0 software (StatSoft Inc., Tulsa, USA). Parameters for the model were calculated by applying a non-linear regression procedure using the Levenberg--Marquardt algorithm. To predict drying data, all of the models were used and were assessed by the coefficient of determination (R^2), root mean square error (*RMSE*) and reduced chi-square (χ^2) parameters. Higher R^2 values and lower χ^2 and *RMSE* values were accepted as better results in the literature [2,21-22]. R^2, χ^2 and *RMSE* are given in Eqs. (4)-(6), respectively:

$$R^2 \equiv 1 - \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{\sum_{i=1}^{n}(MR_{exp,i} - \left(\frac{1}{n}\right)\sum_{i=1}^{N} MR_{exp,i})} \tag{4}$$

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

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2\right)^{1/2} \tag{6}$$

In Eq. (6), predicted and experimental moisture ratio values are represented by MR_{pre} and $MR_{exp.}$ Z is a constant number and is the total number of experiments in the model.

Determination of the effective moisture diffusivity

The mass diffusion is based on Fick's second law. Furthermore, it can be used over a falling-rate period for agricultural drying [4,5]. The analytical solution of Fick's second law - assuming moisture migration because of diffusion, constant diffusion coefficients, negligible shrinkage and temperature while the process of drying is in a state of unsteady diffusion - is given using spherical coordinates in Eq. (7) [24]:

$$MR = \frac{8}{\pi^2} + \left[\sum_{n=1}^{\infty}\frac{4}{a^2\alpha_n^2} exp\frac{Ka^2\alpha_n^2 t}{\pi^2}\right] \times \left[\sum_{n=0}^{\infty}\frac{4}{(2n+1)^2} exp\left[-K(2n+1)^2 t\left(\frac{a}{l}\right)^2\right]\right] \tag{7}$$

where l is one-half the length of cylinder (m), and the value a is taken as the radius of the finite cylinder (m). K is the D_{eff} (effective moisture diffusivity, m^2 s^{-1})×π×a^{-2}. The complexity of Eq. (7) can be simplified as shown in Eq. (8):

$$MR = \frac{8}{\pi^2} exp\left[-Kt\left(\frac{a}{l}\right)^2\right] \tag{8}$$

By taking the *ln* of two sides and putting in the K value from Eq. (9), D_{eff} was estimated from the plot of ln *MR versus t*:

$$\ln MR = \ln\left(\frac{8}{\pi^2}\right) - \frac{D_{eff\times\pi^2}}{a^2}\left(\frac{a}{l}\right)^2 t \tag{9}$$

Determination of the activation energy

The Arrhenius equation describes the relationship of the effective moisture diffusivity to temperature, which is given in Eq. (10) [2,21-22]:

$$D_{eff} = D_0 exp\left(-\frac{E_a}{R(T+273.15)}\right) \tag{10}$$

where D_0 (m^2/s) is the pre-exponential factor of the Arrhenius equation, E_a (kJ/mol) is the activation energy, R (kJ/(mol K)) is the universal gas constant and T (°C) is the temperature.

Rehydration experiments

The experiments of rehydration were carried out in an oven at 20 °C for both drying methods. The dehydrated shrimps were placed in glass beakers including pure water with a mass ratio of 1:100. GFL 2004 (Gesellschaft für Labortechnik, Burgwedel, Germany) was the system of water purification used to obtain pure water. The samples were weighed out at specific time intervals of 30 min after the subtraction of excess water from the surface. Eq. (11) was used to estimate the rehydration ratios (RR) [22]:

$$RR = \frac{W_t - W_{dry}}{W_{dry}} \tag{11}$$

where W_t (kg) and W_{dry} (kg) are the samples' weight at any time and the dry weight, respectively. The rehydration capacity values are means of three replicates.

Color measurement

The color of the dried product is the most significant criteria for product quality and consumers. In the Hunter color system, the *L* parameter represents the lightness or darkness value (100 for white, 0 for black), the *a* parameter represents the greenness and redness values, and the *b* parameter represents the blueness and yellowness values. Measurement was performed for these color parameters before and after the two different drying processes using a hand-held colorimeter (PCE-CSM 1; PCE Instruments UK Ltd., Southampton Hampshire, UK). The instrument was calibrated with the calibration kit in its packaging box before the measurement. Three measurements were recorded for each dried shrimp.

The total change in color (ΔE) of dried samples was estimated using Eq. (12) [25]:

$$\mathrm{E} = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \tag{12}$$

where L_0, a_0 and b_0 are the color values of fresh samples before drying. *L*, *a* and *b* color parameters of samples were measured from five points of every sample just after the drying processes.

Determination of the heavy metal and protein contents

The concentration of heavy metals in dried shrimps was investigated with the Agilent 7700 Series ICP-MS analyzer. The protein content analysis was performed using the Leco FP-528 (3000 Lakeview Ave, USA) protein determinator. The heavy metal content and protein content values are means of three replicates.

RESULTS AND DISCUSSION

Drying curves

The influence of different drying methods and temperatures on the drying behaviour of shrimps is given in Figure 1. Initially, the average moisture content of the shrimp was approximately 4.8824 kg of water/kg of dry matter; for the oven, the moisture content in dried shrimps was reduced to 0.352±0.07 kg of water/kg of dry matter, and for the vacuum oven it was reduced to 0.355±0.143 kg water/kg dry matter. From the curves, it is seen that the increase in temperature decreased the drying times. This is due to the fact that the rate of mass transfer was higher at higher temperatures. The oven drying times were measured at 330, 240 and 210 min for 60, 70 and 80 °C, respectively. The vacuum oven drying times were measured at 190, 120 and 110 min for 60, 70 and 80 °C, respectively. The difference appearing between the drying times is due to the extraction of ambient air with the vacuum pump. Vacuum drying is a process in which materials are dried in a reduced pressure environment, which lowers the heat needed for rapid drying. Vacuum decreases the boiling point of water within foodstuffs and hence facilitates water removal.

In general, the drying process for food products happens in the falling-rate period [26]. The drying rate plots of the two methods related to the moisture content of the dried shrimps are shown in Figure 2. All the three periods of increasing-rate and decreasing-rate periods are seen on the graphs. The drying rate increased as the drying temperature rose.

The oven increasing-rate period is found at 60 °C resulting in 4.8824 to 3.4689 kg of water/kg dry matter, at 70 °C it results in 4.8824 to 3.8337 kg of water/kg dry matter, and at 80 °C it results in 4.8824 to 3.5706 kg of water/kg dry matter. At 60 °C from 3.4689 to 0.4497 kg of water/kg dry matter, at 70 °C from 3.8337 to 0.3210 kg of water/kg dry matter, and at 80 °C from 3.5706 to 0.2865 kg of water/kg dry matter, is calculated as the falling-rate period.

In the vacuum oven, the increasing-rate period is found at 60 °C from 4.8824 to 3.5069 kg water/kg dry matter, at 70 °C from 4.8824 to 3.1888 kg water/ /kg dry matter, and at 80 °C from 4.8824 to 2.9879 kg water/kg dry matter. At 60 °C from 3.5069 to 0.3997 kg water/kg dry matter, at 70 °C from 3.1888 to 0.3895 kg water/kg dry matter, and at 70 °C from 2.9879 to 0.2759 kg water/kg dry matter, is calculated as the falling-rate period.

In general, for the two drying methods, drying predominantly happens in the falling-rate period. Many studies show that in the drying of meat-type products that the major drying phase is during the falling-rate period [13].

Modeling and regression analyses results

For modeling and regression analyses, the experimental results of the two drying methods were

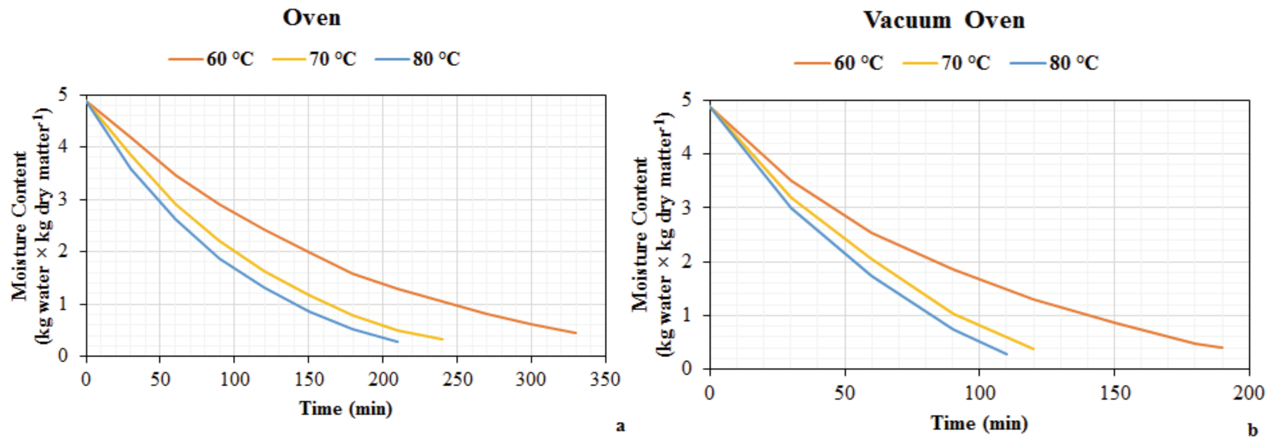

Figure 1. The drying curves of shrimps dried: a) in an oven, b) in a vacuum oven.

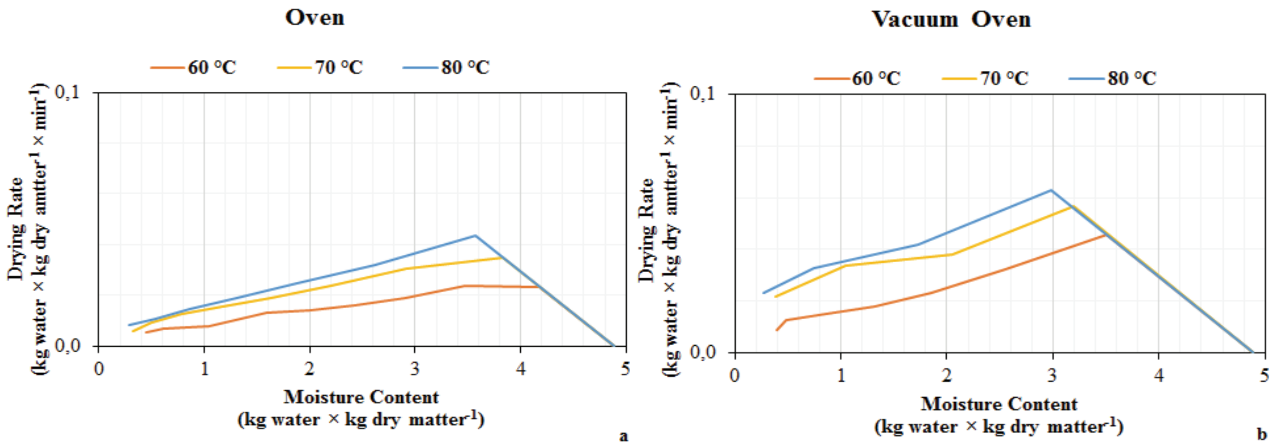

Figure 2. The drying rate curves of shrimps dried: a) in an oven, b) in a vacuum oven.

used with the mathematical models, using non-linear regression analysis. The optimum model was specified in terms of root mean square error (*RMSE*), the coefficient of determination (R^2) and the reduced chi-square error (χ^2), chosen by comparing the other values. R^2 values below 0.994 were not found in any of the drying methods.

In Table 1 it is seen that the Alibas and Midilli and Kucuk models produced the optimum experimental data for the oven and vacuum oven drying methods, respectively. R^2 values were found to be from 0.999834 to 0.999903, and from 0.999493 to 0.999956 for the oven and vacuum oven, respectively. The χ^2 values were found to be from 0.000012 to 0.000016 and from 0.000008 to 0.000144 for the oven and vacuum oven, respectively. *RMSE* values were found to be from 0.0002809 to 0.003673 and from 0.00206 to 0.010381 for the oven and vacuum oven, respectively.

Effective moisture diffusivity values

D_{eff} values were calculated from the equations below. For the oven, D_{eff} values were found to be 1.46×10^{-8}, 2.09×10^{-8} and 2.8×10^{-8} m^2/s for temperatures of 60, 70 and 80 °C, respectively. For the vacuum oven, D_{eff} values were found to be 3.68×10^{-8}, 5.24×10^{-8} and 5.49×10^{-8} m^2/s, for temperatures of 60, 70 and 80 °C, respectively. As seen from the obtained D_{eff} values, the vacuum oven drying had higher diffusion coefficient values than the oven drying. The diffusion coefficient values for the biological materials are within the general range of 10^{-8} to 10^{-12} m^2/s [27]. The temperature increase in meat-type products increases the vapour pressure [13,17,28]. The influence of temperature on the D_{eff} values can be estimated by using Eqs. (13) to (14):

$$\text{Oven} \rightarrow D_{eff} = 7\times10^{-10}T + 3\times10^{-8}\left(R^2 = 0.9985\right) \quad (13)$$

$$\text{Vacuum oven} \rightarrow D_{eff} = 9\times10^{-10}T + 2\times10^{-8}(R^2 = 0.8533) \quad (14)$$

Activation energy values

The estimated values for E_a were 31.65 and 19.72 kJ/mol for the oven and vacuum oven, respectively. Activation energy of oven drying was higher

Table 1. Oven and vacuum oven methods coefficients and statistical data (Avg. R^2>0.9996)

Method	Model	Parameter	Temperature, °C		
			60	70	80
Oven	Alibas	*a*	0.877978	1.703283	1.767061
		k	0.004299	0.005208	0.007785
		n	1.078032	1.015612	0.946261
		b	-0.000379	0.001377	0.001464
		g	0.122651	-0.702933	-0.767077
		χ^2	0.000014	0.000010	0.000001
		R^2	0.999903	0.999953	0.999997
		RMSE	0.002809	0.002091	0.000537
Oven	Midilli and Kucuk	*a*	1.000995	0.999681	0.999564
		k	0.004259	0.006041	0.009947
		n	1.058002	1.073694	0.997310
		b	-0.000142	-0.000218	-0.000337
		χ^2	0.000012	0.000013	0.000006
		R^2	0.999899	0.999919	0.999968
		RMSE	0.002862	0.002738	0.001718
Oven	Aghbashlo	k_1	0.005336	0.007812	0.009611
		k_2	-0.000752	-0.001288	-0.001190
		χ^2	0.000016	0.000008	0.000045
		R^2	0.999834	0.999929	0.999645
		RMSE	0.003673	0.002567	0.005793
Vacuum Oven	Aghbashlo	k_1	0.010026	0.011997	0.013738
		k_2	-0.001021	-0.003401	-0.003943
		χ^2	0.000144	0.000193	0.000203
		R^2	0.998826	0.998917	0.998949
		RMSE	0.010381	0.010767	0.011043
Vacuum Oven	Midilli and Kucuk	*a*	1.000271	0.999609	0.999879
		k	0.014127	0.013263	0.016015
		n	0.908217	0.963495	0.950995
		b	-0.000578	-0.001556	-0.001752
		χ^2	0.000008	0.000226	0.000046
		R^2	0.999956	0.999577	0.999920
		RMSE	0.002006	0.006728	0.003036
Vacuum Oven	Logarithmic	*a*	1.096500	1.340654	1.323021
		k	0.009246	0.009654	0.011297
		c	-0.102732	-0.342574	-0.324664
		χ^2	0.000074	0.000124	0.000047
		R^2	0.999493	0.999538	0.999839
		RMSE	0.006819	0.007031	0.004315

than vacuum oven drying. The activation energy is inversely related to moisture content, and vacuum drying facilitates moisture removal from food. The values for food product activation energy varied over a range from 12.7 to 110 kJ/mol [27].

Rehydration ratio values

Rehydration characteristic ability is an important feature of food products. It can be addressed as a measure of damage as a result of the drying process. The food product is structurally modified by the drying process and this modification changes water absorption [4,5]. Using Eq. (11), the rehydration ratio values are estimated with the increase in the temperature causing greater rehydration ratio, in that increasing temperature causes decreased drying time. Swelling ratios of oven-dried shrimps remained at 42.85±0.15, 47.19±0.35 and 50.75±0.17% for 60, 70 and 80 °C, respectively, at 20 °C in 150 min. Swelling ratios of vacuum oven-dried shrimps remained at 32.13±0.12, 45.59±0.21 and 57.91±0.19% for 60, 70 and 80 °C, respectively, at 20 °C in 120 min. The ratio increased due to the increased drying temperature for both methods.

The porosity of the dried products decreased with the increase in drying time. The rehydration process occurs in a shorter time for the vacuum oven method than the oven method, due the more damage occurring in the oven to the pores. The swelling ratios are shown in Figure 3.

Color values

L, *a* and *b* values of the dried shrimps using different methods are shown in Table 2. *L* value changes relate to decreasing drying times for the two methods. *L* values change between 21.74 and 29.03 for the oven method and between 23.48 and 43.06 for the vacuum oven method. The highest and the lowest redness values for *a* were attained in the oven and vacuum oven, respectively. Redness values, *a,* for the oven method changed between 1.51 and 5.04 and for the vacuum oven method between 0.44 and 4.12. The highest and the lowest yellowness values for *b* were obtained in the oven dryer and vacuum oven dryer, respectively. Yellowness values, *b,* for the oven method changed between 3.13 and 7.14 and for the vacuum oven method between 1.58 and 4.75. Drying time and temperature affects the change in color and the highest *L, a* and *b* values of the dried shrimps were obtained from the oven-drying method. The drying temperature increases as the *L* and *b* values increase, but *a* value decreases for both methods.

For the comparison of the total color change, the highest color change is obtained in the oven due to the higher drying times and the lowest color change in the vacuum oven dryer due to the lower drying times.

Analyses of heavy metal content

The heavy metals investigated in the shrimp included arsenic, lead, cadmium, mercury, copper, zinc and iron. These metals can be divided into two classes: toxic (As, Pb, Cd, Hg) and essential elements (Cu, Zn, Fe) [29,30]. For both methods, the heavy metal content analyses were performed for each temperature. Permissible upper limits of heavy metals change according to national and international

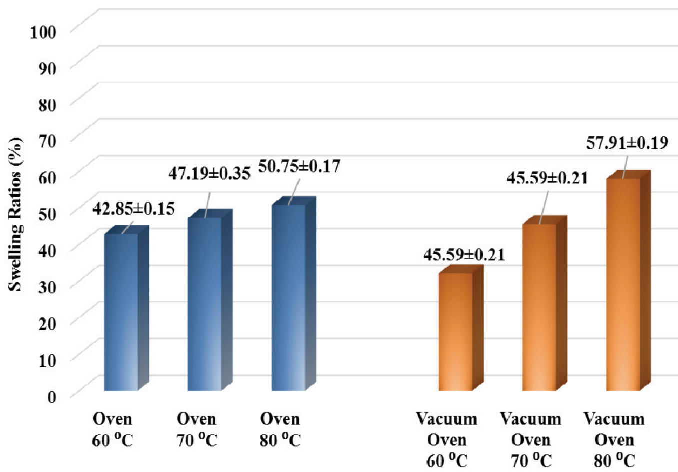

Figure 3. Comparison of swelling ratios between both methods (%).

Table 2. Color values of shrimp dried with oven and vacuum oven methods

Temperature, °C	*L*	*a*	*b*	*ΔE*
Fresh	60.18±0.42	5.36±0.09	1.42±0.01	-
		Oven		
60	21.74±0.18	5.04±0.09	3.13±0.02	38.48±0.24
70	27.59±0.15	3.56±0.10	5.81±0.04	32.93±0.27
80	29.03±0.11	1.51±0.11	7.14±0.06	31.90±0.31
		Vacuum Oven		
60	23.48±0.17	4.12±0.07	1.58±0.03	36.72±0.25
70	33.67±0.14	2.14±0.05	3.57±0.06	26.79±0.29
80	43.06±0.10	0.44±0.04	4.75±0.08	18.12±0.33

standards: FAO (Food and Agriculture Organization) (1983), WHO (World Health Organization, 1989), MAFF (Ministry of agriculture, fisheries and food in the UK, 1995), European Commission (2008, 2014) and Turkish Food Codex (2002) values are given in Table 3 [31-38].

Table 3. Maximum permissible limits (mg/kg) of heavy metal changes according to national and international standards

Standard	As	Pb	Cd	Cu	Zn	Fe	Hg
FAO (1983)	-	0.5	0.5	30	40	-	-
WHO (1989)	-	2	1	30	100	-	-
MAFF (1995)	-	2	0.2	20	50	-	0.5
EC (2008,2014)	-	0.3	0.5	-	30	-	1
Turkish Food Codex (2002)	1	0.5	0.5	20	50	-	0.5

The highest and lowest arsenic content in shrimp were found to be 133.8±5.5 to 99.9±4.1 µg/g, and 135.5±5.5 to 102.7±4.2 µg/g for the oven method and vacuum oven method, respectively. The quantity of Pb changed between 0.065±0.011 to 0.228± ±0.0033 µg/g, and between 0.228±0.0033 and 0.1156 µg/g for the oven method and vacuum oven method, respectively. The quantity of Cd changed between 0.0288±0.0014 and 0.0174±0.0005 µg/g, and between 0.0379±0.0011 and 0.03411±0.001 µg/g for the oven method and vacuum oven method, respectively. The quantity of Cu changed between 11.42±0.32 and 4.08±0.12 µg/g, and between 8.74± ±0.25 and 3.63±0.1 µg/g for the oven method and vacuum oven method, respectively. The quantity of Zn changed between 46.48±1.32 and 34.32± ±0.97 µg/g, and between 43.25±1.23 and 35.9±1.02 µg/g for the oven method and vacuum oven method, respectively. The quantity of Fe changed between 38.78±5.9 and 13.07±0.2 µg/g, and between 132.2±2 and 3.49±0.05 µg/g for the oven method and vacuum oven method, respectively. The quantity of Hg changed between 1.42±0.02 and 0.7±0.01 µg/g, and between 1.2±0.02 and 0.63±0.01 µg/g for the oven method and vacuum oven method, respectively. It was determined that the heavy metal levels of the dried shrimps were below the threshold values. No information could be found about maximum iron level in shrimp samples in any of the standards. The heavy metal content of dried shrimps is given in Table 4.

Protein content analyses

Shrimps have a high protein content like other aquatic creatures. The protein contents changed from 15 to 20%. In addition, the shrimps' protein content before drying was 19.57% [39]. After the drying process, for both methods, the protein ratio increased as the drying temperature increased. Protein rates changed between 83.413 and 85.986% and between 76.882 and 84.152% for the oven method and vacuum oven method, respectively. For both drying procedures, the protein content for dried shrimp is higher than for undried shrimp.

CONCLUSION

This study shows the influences of different drying methods on the quality and physical properties of dried shrimps. Oven and vacuum oven drying curves and the kinetics of shrimps were simultaneously studied at 60, 70 and 80 °C temperatures. Vacuum oven drying time was shorter than oven drying due to the extraction of ambient air with the vacuum pump. The Alibas model and Midilli and Kucuk model gave the best fit for the drying data for oven and vacuum oven drying methods, respectively. The D_{eff} values obtained for the vacuum oven and oven drying methods were found to be 5.49×10^{-8} and 2.8×10^{-8} m^2/s, respectively. The E_a values obtained for the vacuum oven and oven were found to be 19.72 and 31.65 kJ/mol, respectively. The rehydration ratio increased with increasing drying temperature in both methods. In both studied systems, the L and b values increased with increasing drying temperature while a values decreased. Heavy metal analysis showed that the metal content of the dried shrimps was acceptable for human consumption when considering nutritional and toxic levels. For both drying procedures, the protein content of dried shrimp (~85%) was significantly higher than of the undried (~20%). As a continuation of this research, we will study the drying of shrimp

Table 4. Heavy metal contents of dried shrimps (µg/g)

Sample name	As	Pb	Cd	Cu	Zn	Fe	Hg
Oven 60 °C	133.8±5.5	0.065±0.011	0.0288±0.014	11.42±0.32	46.48±1.32	38.78±5.9	1.42±0.02
Oven 70 °C	116.0±4.7	0.0427±0.006	0.0192±0.0006	5.480±0.16	36.16±1.03	13.28±0.2	1.16±0.02
Oven 80 °C	99.9±4.1	<0.011	0.0174±0.0005	4.08±0.12	34.32±0.97	13.07±0.2	0.7±0.01
Vacuum Oven 60 °C	135.5±5.5	0.228±0.0033	0.19±0.0059	3.63±0.1	35.9±1.02	132.2±2	0.63±0.01
Vacuum Oven 70 °C	128.7±5.3	0.380±0.055	0.0379±0.0011	8.74±0.25	43.25±1.23	16.71±0.25	0.68±0.01
Vacuum Oven 80 °C	102.7±4.2	0.116	0.03411±0.001	5.83±0.17	39.08±1.11	3.49±0.05	1.2±0.02

with modern methods and we will compare the advantage and disadvantages of modern and conventional methods.

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NAUČNI RAD

KINETIKA SUŠENJA I KARAKTERISTIKE ŠKAMPA SUŠENIH KONVENCIONALNIM METODAMA

Osnovna svrha ovog rada bila je istraživanje uticaja različitih metoda sušenja na fizička i svojstva kvaliteta sušenih škampa. Račići su sušeni konvencionalnim metodama na 60, 70 i 80 °C između 330 min do 210 min, odnosno 190 do 110 min, u rerni, odnosno u vakuumskoj peći. Vreme sušenja se skraćuje upotrebom vakuum pumpe. Proučavana je kinetika sušenja škampa i izračunata je efektivna difuzija vlage i energija aktivacije za obe metode. Alibasov model, odnosno Midilli-Kucuk model najbolje fituju eksperimentalne podatke sa visokim koeficijentom determinacije (R^2) za rernu, odnosno vakuum peći. Finalni osušeni proizvodi su okarakterisani ispitivanjem karakteristika boje, sadržaja teških metala i analizom proteina. Odnos rehidratacije je, takođe, određen za dehidrirane škampe. Uslovi sušenja su uticali na karakteristike boje, tako da su škampi sušeni u rerni i vakuum peći pokazivali povećanje vrednosti svetline i žute boje i smanjenje vrednosti crvenila. Koncentracije As, Pb, Cd, Hg, Cu, Zn i Fe u sušenim škampima bile su u prihvatljivim granicama. Sadržaj proteina u sušenim škampima (~85%) je veći od nesušenih škampa (~20%).

Ključne reči: škampi, kinetika sušenja, rehidratacija, sadržaj proteina, analiza boje, teški metal.