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Dehydration kinetics of salmon and trout fillets using ultrasonic vacuum drying as a novel technique

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ABSTRACT

In this study, a novel ultrasonic vacuum (USV) drying technique was used to shorten the drying time of fish fillets. For this purpose, ultrasonic treatment and vacuum-drying were simultaneously performed to dehydrate salmon and trout fillets at 55 °C, 65 °C, and 75 °C. In addition, the USV technique was compared with vacuum-drying and oven-drying techniques. The dehydration kinetics of the fillets was successfully described by seven thin-layer drying models with R^2 range between 0.944 and 1.000. Depending on drying temperatures and fish species, the drying times could be shortened using the USV technique between 7.4% and 27.4% compared with vacuum-drying. The highest effective moisture diffusivity was determined in the fillets dried with the USV technique and they increased with increasing drying temperatures. Ultrasonic treatment accelerated the vacuum drying process for the fillets; therefore, this technique could be used to improve the efficiency of vacuum-drying for the fillets.

1. Introduction

Fish is a food product with high protein content and nutritional value. However, consumption of this beneficial product throughout the year is very difficult because of the many changes that occur in fish's enzymatic and microbial activity, which result in the deterioration of fish. Therefore, different methods have been improved to preserve fish and similar products. Drying is one of the widely used methods because it is both efficient and cheap [1].

Drying methods are based on removing the water from fish. The process of drying fish can basically be classified as thermal drying (air drying, oven drying, microwave heating, etc.), osmotic dehydration and mechanical dewatering [2]. There has been a lot of research done on drying fish using different methods, including sun drying [3], solar drying [4,5], hot air drying [6] and microwave-hot air drying [2]. These different drying methods each have their own distinct advantages.

In recent years, there have been many advances in food drying technology including pre-treatments, techniques, equipment and quality. Recent research was focused on methods such as microwave-assisted drying, ultrasound-assisted drying, high electric field drying, heat pump drying and refractance window techniques [7].

Ultrasonic treatment may be very effective in reducing the temperature or treatment time in the dehydration processes of porous materials [8]. Because ultrasonic vibrations are capable of increasing mass and heat transfer in food, a lot of research has been done on food dehydration, using convective drier assisted by ultrasound [8,9], using ultrasound as pretreatment [10] and ultrasound-assisted osmotic drying methods [11,12]. However, no research could be found on ultrasonic vacuum drying except in the study of Başlar et al. [13].

The ultrasonic vacuum (USV) drying technique is a novel technique for food drying. It is known that the technique was first reported by Başlar et al. [13] for food dehydration. The technique is based on a combination of ultrasonic treatment and vacuum drying for shortening the drying time. In the technique, vacuum drying creates an environmental pressure that is much less than the atmospheric pressure and therefore evaporates water at low temperatures. Also, vacuum drying increases the drying rate by accelerating water transfer. The ultrasonic treatment, which is the other main component of the technique, simultaneously assists heat transfer and accelerates the water transfer from the interior to the surface of the material by using mechanical waves. Therefore, the novel drying technique is composed of vacuum drying, which reduces environmental pressure for rapid drying, and an ultrasonic process, which accelerates heat and mass transfer. Başlar et al. [13] reported that the drying time of beef and chicken meat was decreased to the percentages ranging from 8.3% to 37.5% and from

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Nomenclature

D_0	pre-exponential factor for the Arrhenius equation (m^2/s)
D_{eff}	effective moisture diffusivity (m^2/s)
E_a	activation energy (J/mol)
k	constant of drying velocity (min^{-1})
L	half thickness (m)
M	moisture content of sample (kg water/kg dry matter)
M_0	initial sample moisture (kg water/kg dry matter)
M_e	equilibrium moisture (kg water/kg dry matter)
MR	moisture rate
$MR_{exp,i}$	experimental moisture ratio values of ith observation
$MR_{pre,i}$	predicted moisture ratio values of the ith observation,
M_t	moisture contents of samples at time t (kg water/kg dry matter)
$M_{t+\Delta t}$	moisture contents of samples at time $t + \Delta t$ (kg water/kg dry matter)
n	dimensionless drying constant
N	number of observations
R	gas constant (8.3145 J/mol K)
R^2	determination coefficient
t	drying time (s, min or h)
T	drying temperature (K)
z	number of constants in the drying models
χ^2	chi-square

10.8% to 42.1%, depending on drying temperatures. Also, it was reported that the consumed energy markedly decreased in this novel technique for beef and chicken meats dried at 65 °C and 75 °C, when compared with vacuum or oven drying processes. However, the highest effective moisture diffusivity and the lowest drying time were determined in the meats dried with the USV technique. Besides more research is need about effect of USV technique on sensorial, visual and biochemical quality parameters of foods.

The objective of this study is the ultrasonic vacuum (USV) drying technique as a novel process for drying fish fillets (salmon and trout) with oven and vacuum drying at different techniques 55 °C, 65 °C and 75 °C. Also, dehydration kinetic models were fitted to the obtained data and determined effective moisture diffusivity. The study presents firstly effect of USV technique on drying properties of fish fillets.

2. Materials and methods

2.1. Materials

The salmon and trout, used in the present study, were purchased from a local fish market in Istanbul, Turkey. The weight range of the salmon and trout was 950–1100 g and 450–550 g, and their length range was 45–50 cm and 25–30 cm, respectively. Fillets were prepared by removing the head, bones and tail from the fishes. The weight and thickness of the fillets was set 35 g and 10 mm, respectively. The physicochemical properties of the fishes are presented in Table 1.

2.2. Physicochemical analysis

Dry matter and ash content of the fillets were determined according to AOAC [14]. The protein and fat content of the fillets were determined with Kjeldahl and Soxhlet methods according to the detailed method used by Başlar et al. [13].

Table 1
Physicochemical properties of the fillets.

Component	Salmon fillets	Trout fillets
Dry matter (%)	36.04 ± 0.49	24.28 ± 0.23
Protein (%)	22.64 ± 0.87	17.56 ± 0.56
Fat (%)	12.61 ± 0.90	5.57 ± 0.32
Ash (%)	0.58 ± 0.05	0.76 ± 0.09

2.3. Drying the fillets

Our research team conducted a study using the ultrasonic vacuum (USV) inorder to compare the drying properties of the vacuum and oven drying techniques at 55 °C, 65 °C and 75 °C. The salmon and trout fillets was dried as the flowchart shows in Fig. 1. While using the USV technique, ultrasonic treatment was simultaneously applied to the fillets in a conical flask with a vacuum (Fig. 2). Ultrasonic was transmitted an ultrasonic bath (Daihan WUC-D10H, South Korea) with a frequency of 40 kHz and amplitude of 100% and actual power of 210 ± 1 W. The tank capacity of the laboratory bath was 10 L (d: 24 cm, w: 29 cm, and h: 15 cm), and it was filled with about 8 L of pure water (d: 24 cm, w: 29 cm, and h: 11.5 cm). The flask containing meat was placed about 3 cm above the bottom of the ultrasonic bath.

The vacuum was supplied from a vacuum pump (KNF N838.3KT.45.18, Germany) with 15 mbar ultimate pressure and 22L/min pump speed. The design of the drying technique is shown in Fig. 2. The treatment temperature of the ultrasonic bath was fixed at 55 °C, 65 °C, and 75 °C by circulation and was measured using a thermocouple (k-type, Omega Engineering Inc., USA). For vacuum drying, the same system shown in Fig. 2 was used, without the ultrasonic treatment, in order to better compare with the USV technique. The oven drying technique was performed using a forced air circulation oven (Memmert UF110, Germany) with 1.3 m/s constant air velocity [13].

2.4. Total energy consumption

The total energy consumption of the drying experiments was measured using a digital energy meter (PeakTech 9035,

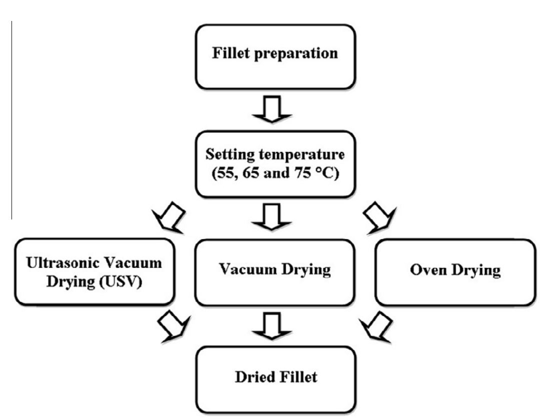

Fig. 1. The flowchart of the drying experiment.