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Ultrasonic vacuum drying technique as a novel process for shortening the drying period for beef and chicken meats

Mehmet Başlar *, Mahmut Kılıçlı, Omer Said Toker, Osman Sağdıç, Muhammet Arici

Yildiz Technical University, Chemical and Metallurgical Engineering Faculty, Food Engineering Department, 34210 Istanbul, Turkey

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ABSTRACT

In the present study, a novel drying technique using a combination of ultrasound and vacuum dehydration was developed to shorten the time for the drying of beef and chicken meats. The meats were dried using three different techniques, namely ultrasonic vacuum (USV) drying, vacuum drying and oven drying at 55, 65 and 75 °C. The meats dried faster with USV than with the vacuum and oven drying techniques. The drying time for the USV, vacuum and oven drying techniques at 75 °C was determined as 300, 480 and 750 min for beef and 330, 570 and 780 min for chicken, respectively. The drying rate was significantly influenced by the drying techniques and temperatures. The lowest energy consumption was determined in the USV technique. The drying data were successfully fitted to 10 models (R^2: 0.9140–0.9991). According to the results, the USV drying technique shortened the drying period of beef and chicken.

Industrial relevance: Beef and chicken meats dried faster with the USV drying method than with the vacuum and oven drying techniques. The novel drying technique could be used to improve efficiency of the vacuum drying technique. Combination of ultrasound and vacuum treatment consumed lower energy compared with oven and vacuum drying.

1. Introduction

Foods tend to deteriorate chemically and microbiologically during storage due to their high water activity, which negatively influences the nutritional value and sensory properties of the product as well as the formation of detrimental compounds. Therefore, various preservation methods have been improved to extend the shelf life of products since ancient times. Drying is one of the oldest preservation techniques in which mass and heat transfers occur simultaneously (Akpinar, 2006). Meat products are dried for different aims such as powdered meat, fermented sausages and dry-cured hams (Arnau, Serra, Comaposada, Gou, & Garriga, 2007). Dried meats are used as an ingredient in various food products; for instance, dried chicken, sliced or cubic, can be added to ready-to-eat noodle formulations (Natharanakule, Kraiwanichkul, & Soponronnarit, 2007). Hot air drying is the most widely used method; however, it causes the deterioration of aroma compounds (Timoumi, Mihoubi, & Zagrouba, 2007), the degradation of nutritional compounds (Suvarnakuta, Devahastin, & Mujumdar, 2005) and lipid oxidation (Toujani, Hassini, Azzouz, & Belghith, 2013). Drying is the most expensive step during manufacturing of dried meat products due to the time and effort to control the system and preserve the product and the energy consumed during the drying process (Traffano-Schiffo, Castro-Giráldez, Fito, & Balaguer, 2014). Since the meat sector is one of the most important sectors in the European Union (Traffano-Schiffo et al., 2014), creating a new drying technique as an alternative to traditional ones to decrease cost and increase the quality of the dried product is very important for the food industry.

In recent years, attempts have been made to shorten the drying period to improve the energy efficiency of the drying process and the quality of the dried products (Chou & Chua, 2001). The quality of the dried products could be improved by decreasing the drying temperature or the drying period. Therefore, instead of oven or convective drying, vacuum drying is widely preferred. Moreover, some pretreatments are used in order to speed up the drying process. Ultrasound treatment is widely used as a pretreatment technique to accelerate drying. Applying ultrasound interrupts the continuity of the membranes, and thus increases the mass transfer rate between the cell and its extracellular surroundings (Nowacka, Wiktor, Śledź, Jurek, & Witrowa-Rajchert, 2012). Ultrasound treatment is connected to drying during the process and as a preliminary treatment positively affects the drying process in terms of improving the quality of the dried products and reducing the energy consumed during drying. Ultrasound can be applied to improve the convective heat transfer coefficient (Lima & Sastry, 1990), to accelerate freezing rates during freezing of potatoes (Li & Sun, 2002) or to increase mass transfer for different products and processes such as brining of meat and cheese (Muralidhara, Ensminger, & Putnam, 1985; Sajas & Gorbatow, 1978). However, although ultrasound treatment can be used in many ways to accelerate drying processes, it has not been connected with vacuum drying. Therefore, in the present study, ultrasound

* Corresponding author. Tel.: +90 2123834579; fax: +90 2123834571.
E-mail address: mbaslar@yildiz.edu.tr (M. Başlar).

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and vacuum processes were combined as a novel drying technique. In this method, the advantages of both processes were used to shorten the drying period. To our knowledge, no studies on the use of ultrasound and vacuum combined to dry meat or any other food products have been conducted.

The objective of the present study is to develop a new drying method by combining ultrasound and vacuum processes. For this aim, beef and chicken meats were dried with oven, vacuum and ultrasonic vacuum techniques at different temperatures (55 °C, 65 °C and 75 °C). The drying data were modeled with various drying models to determine the change in the moisture content of the meat samples as a function of drying time.

2. Materials and methods

2.1. Materials

Top round beef and chicken breast, used as raw material in the present study, were obtained from a butcher in Istanbul, Turkey. Top ground beef meat was obtained from beef at 2-years old (Balıkesir, Turkey). Chicken breast meat was obtained from broiler chicks (Ross 308) at 6 weeks (Erpiliç A.Ş., Bolu, Turkey). Physicochemical properties of the meats analyzed are presented in Table 1. Beef meat and chicken breast were cut to a size of 5 cm × 5 cm × 1 cm (30 ± 0.5 g).

2.2. Physicochemical properties of meat samples

Dry matter, ash and protein content of meat samples was determined in the present study. Dry matter content of sliced meat samples was determined by a modified procedure of AOAC (1995). Meat samples were dried at 105 °C by drying oven until constant weight was reached. Ash content of the samples was determined by incinerating them at 600 °C for 5 h in a muffle oven (Daihan, F-12, South Korea). Protein content of the samples was determined by the Kjeldahl method. The Kjeldahl system consists of an infrared heater, a distillator and a titrator (Behr InKjel 625P/S5/TB1, Germany). Twenty milliliters of sulfuric acid was added to 2 g meat samples and then 2 Kjeldahl tablets (SIAL) were added. The prepared mixture was burned with an infrared Kjeldahl heater according to the following conditions: 50% power for 30 min, 70% for 30 min and 100% for 60 min. The maximum heating power of the system (100%) is 1500 W. Then the burned solution was diluted with NaOH (40%), boric acid (5% w/v) was added and then this mixture was titrated with 0.1 N HCl using an automatic titrator until 4.6 pH was reached. The factor 6.25 was used for calculation of protein content. Fat content of samples was determined by the Soxhlet method. Fat found in meat samples was extracted from dried meat samples with hexane by the Soxhlet extraction system (Daihan, WHM-12293, South Korea). After evaporation of hexane by a rotary evaporator, the extracted fat was weighed and it was divided by initial weight of the meat samples to determine fat content.

2.3. Drying of meat samples with different techniques

The USV technique is composed of an ultrasound water bath (Daihan, WUC-D10H, South Korea) and a vacuum pump (KNF N838.3KT.45.18, Germany) as shown in Fig. 1. In this technique, meat samples were put into a conical flask which was connected to a vacuum pump as seen in Fig. 1. Then vacuum treated sample was sonicated at 40 kHz using an ultrasonic bath (Daihan, WUC-D10H, South Korea) (amplitude: 100%, power: 590 W, volume: 10 L). The temperature of the ultrasound water bath was controlled (thermocouple (k-type, Omega Engineering Inc., USA)) and fluctuation of the water temperature in the bath was prevented by circulation of water. The weight of the meat samples dried with three different techniques at different temperatures as mentioned above was measured at each 30 min. All weighing processes take 15 s after removing of the sample from the drying system, which was important for obtaining reproducible drying curves (Jamradloedluk, Nathakaranakule, Soponronnarit, & Prachayawarakorn, 2004).

Table 1
Physicochemical properties of beef and chicken meats used in the present study.

	Beef	Chicken
Dry matter (%)	25.94 ± 0.21	25.29 ± 0.35
Protein (%)	22.89 ± 0.20	21.86 ± 0.45
Fat (%)	1.61 ± 0.05	1.75 ± 0.08
Ash (%)	1.23 ± 0.04	1.13 ± 0.02

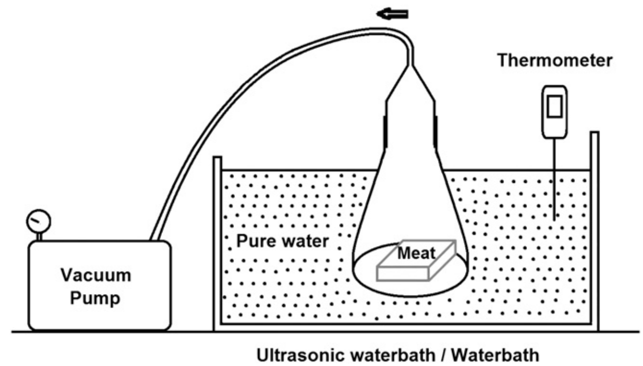

Fig. 1. A schematic view of the novel drying technique composed of ultrasound and vacuum systems.

2.4. Mathematical modeling of drying kinetics

Both meat samples were dried with US–vacuum (USV) drying, vacuum drying and oven drying at 55, 65 and 75 °C until about 25% moisture content (d.b.).

$$MR = \frac{w - w_e}{w_0 - w_e} \tag{1}$$

where w is the moisture content at any time, w_e is the equilibrium moisture content and w_0 is the initial moisture content of the meat samples. In the present study, this equation was simplified to $MR = w / w_0$ described by Rayaguru and Routray (2012) since w_e was very small compared to w or w_0.

In the present study, the obtained drying data (time versus MR) were modeled by 10 different models and equations of them are presented in Table 2. In these equations, MR represents the moisture ratio of the samples at any time and t is the drying time. The obtained data were fitted to the models and their corresponding constants were calculated using Statistica program software (StatSoft Inc., USA). Moreover, drying rate (DR) and effective moisture diffusivity (D_{eff}) were calculated according to Eqs. (2) and (3), respectively (Doymaz, 2013) for both beef and chicken meat samples.

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

where M_t and $M_{t+\Delta t}$ are the moisture content of the samples at time t and $t + \Delta t$, respectively, and t is the time (min).

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \tag{3}$$

where D_{eff} is the effective moisture diffusivity (m^2/s) and L is the half thickness of meat slab.