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Extended Abstract

Experimental Investigation of Fish Fillet Drying Process using IR Radiation

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Abstract

The aim of this study was to use the Response Surface Method (RSM) model to design, test and optimize the drying process of fillets of common carp (*Cyprinus carpio*) using infrared radiation. The power of infrared radiation was 83, 104 and 125 watts and the power of the IR-lamp was 250 watts and its distance from the fish fillet was 5 cm. Pieces of fish fillets were weighed at intervals of 60, 120 and 180 min with a digital scale with an accuracy of 0.01 g. Radiation power (A) and irradiation time (B) were effective in reducing the amount of moisture and the effect of quadratic radiation power and irradiation time were significantly more effective in comparison with their linear effect in reducing the amount of moisture. However, the power of radiation played a more important role compared to the time of radiation. The drying rate of the fillets increased with lower irradiation time and higher irradiation power, so that the drying speed of the fillets improved in the minimum irradiation time (60 min) under high irradiation power. Effective moisture permeability was reduced at low irradiance and low radiation time. Based on central composite design models, treatment 2 with 125 watt power and time of 60 min (moisture of 1.32 g of water/g of sample weight, drying speed of 0.022 g water/g sample weight per minute and effective moisture permeability 1.25846E-007 m^2/s) improved the shelf life of fish fillets.

Keywords: Drying, Fish fillet, Infrared radiation, Response Surface Method

Introduction

Fish is among a class of aquatic vertebrates which is an important source of high quality protein in human diet. It contains about 80% of water in its fresh state and it is a highly perishable food product with a very short shelf life. Fish is a food product with excellent nutritional value, providing high quality protein and a wide variety of vitamins and minerals including vitamins A and D, phosphorus, magnesium, selenium and iodine (Adeyeye, 2019). Dried fish are popular seafood in Asian countries including China, Korea and Japan because of their ease of availability and taste. The physicochemical changes in the fish product after harvest leads to spoilage which begins as soon as the fish dies. Spoilage is a metabolic process which renders food product undesirable or unacceptable for human consumption due to changes in sensory and nutritional characteristics. In other to prevent spoilage in food product, several important preservative techniques to maintain quality is employed and these include processes like smoking, cooling, sun-drying, and drying in electrical and solar dryers and also the use of pre-treatments such as salt, which helps to retard bacterial action (Tirawanichakul, Kaseng, & Tirawanichakul, 2011). Drying of fish is important due to the fact that it preserves fish by inactivating enzymes and removing the moisture necessary for bacterial and mould growth. Fish in its dried form is one of the most important exported marine products in many countries such as Turkey, Iran, India, Thailand, Russia, China, Malaysia and United states (Ikrang & Umani, 2019). Drying is a complex thermal process in which unsteady heat and moisture transfer occur simultaneously. Diffusivity is used to indicate the flow of moisture out of material during drying and is considered to be a relevant transport property necessary for the correct modelling and understanding of the food drying process. In addition, improving drying processes by reducing energy consumption and providing high quality product with minimal increase in economic input has become the goal of modern drying (Jain & Pathare, 2007).

Infrared heating is one such method of removal of moisture from foods. IR is an electromagnetic radiation which is in the region of 0.78-1000μm. It is transmitted and absorbed by food surface and gets changed into heat. Generally far-IR region (3-1000μm) is used for food processing since most of the food materials are having the ability to absorb IR of in this region. IR drying provides less drying time, highly energy efficient, uniformity in drying and good quality dried products (Mujumdar, 2015).

Response surface methodology (RSM) is a statistical and mathematical method that has been developed and successfully used to improve and optimize drying processes in food research and industry. RSM has been used to reduce in the number of experimental trials needed to evaluate multiple parameters and their interactions, thus, requiring less time. RSM has been widely used to improve product quality in the drying process and in new product development, as well as improving existing product design (Zhao, Jiang, & Eun, 2017).

Ikrang & Umani (2019) to evaluate the Optimization of process conditions for drying of catfish (*Clarias gariepinus*) using Response Surface Methodology (RSM). It was concluded from their study that the solution temperature and drying time were the most pronounced factors affecting moisture content of catfish sizes during electrical oven drying process and closely followed by product thickness and salt concentration. Response surface methodology was effective in optimizing the drying process parameters for the drying process of the different sizes of catfish in an oven. Ismail & Kocabay (2018) to investigate the effect of microwave and infrared drying methods on the drying rate, time and color, to fit the experimental data to seven different mathematical models, and to compute effective diffusivity and activation energy of rainbow trout. They reported that the moisture content of the fish samples decreased but the final moisture with the microwave was statistically higher than the infrared. As the infrared and microwave drying power increased, drying rate increased and drying time decreased as expected. Seven different thin layer drying models were evaluated and the logarithmic model gave the best representations of the drying data for all the experimental conditions. The microwave drying had less influence on the color of fish samples that the infrared drying.

As common carp one of the most consumed fish food product in world, it can be preserved by employing better processing techniques to increase its shelf life while still retaining its nutritional content. Hence, the present study aim to use response surface methodology (RSM) as a tool to optimize the processing conditions (drying temperature and drying time) to obtain a minimum moisture content for dried common carp.

Materials and methods

Common carp (*Cyprinus carpio*) were purchased from a local farm in Khuzestan Province, Iran. The fish was washed, weighed, eviscerated and cleaned. The weight of fish was 1650±4.50 g. Dried fish were cut into pieces of approximately 5×15 cm. Drying experiments were carried out in a moisture analyzer with one 250 W halogen lamp. During the infrared drying process, the sample were evenly separated and spread over the entire pan. The power level was set in the control unit of equipment. The drying experiments were done at infrared power levels of 83, 104 and 125 W. Drying was finished when the moisture content of the samples was approximately 0.18±0.01 g water/g dry matter. The dried products were put in a desiccator and cooled to room temperature.

Moisture contents of fish samples during the thin layer drying experiments were expressed in dimensionless form as the moisture ratios MR using Eq. (1) (Darvishi, Azadbakht, Rezaeiasl, & Farhang, 2013):

$$MR=\frac{M_t-M_e}{M_0-M_e} \quad (1)$$

Where; M_t is the mean fish samples moisture content at a specific drying time (t), Mo is the initial moisture content, M_e is the equilibrium moisture content all expressed as g water/g dry matter. As the air humidity in the drying chamber is not constant, the expression was reduced to (Eq. 2):

$$MR = M_t / M_o \quad (2)$$

Where M_e was assumed to be negligible. The drying rates (DR) of fish samples were calculated using Eq. (3) (Omodara & Olaniyan, 2012):

$$DR = \frac{M_t-M_{t+\Delta t}}{\Delta t} \quad (3)$$

Where: $M_{t+\Delta t}$ is the moisture content of fish samples at t + Δt (g water/g dry matter), Δt is the time interval between samplings. Moreover, effective moisture diffusivity (D_{eff}) values were calculated using Eq. (4) for the fish samples (Okos, Campanella, Narsimhan, Singh, & Weitnauer, 2006). Based on Fick's second law, D_{eff} was calculated using Crank's equation

$$MR = \frac{M_t-M_E}{M_0-M_e} = \frac{8}{\pi^2} exp\left[-\frac{\pi^2 D_{eff}\, t}{4L^2}\right] \quad (4)$$

Where, D_{eff} is the effective moisture diffusivity (m^2/s); L is the half-thickness of the fish slab (cm) and t is the drying time (s). A plot of in MR versus drying time should give a straight line with a slope K as shown in Eq. (5).

$$K = \frac{\pi^2 D_{eff}}{4L^2} \quad (5)$$

Using the value of the slope, the effective moisture diffusivity could be determined. Temperature was not a directly measurable quantity in the microwave or infrared during the drying process. The dependence of the D_{eff} on the ratio of microwave and infrared output power to sample amount was evaluated using an Arrhenius type Eq. (6):

$$D_{eff} = D_0 exp\left[-\frac{E_a m}{P}\right] \quad (6)$$

Where; D_0 is the pre-exponential factor of the Arrhenius equation (m^2/s), E_a is the activation energy (W/g), P is the microwave or infrared power level (W) and m is the sample weight (g). Activation energy was calculated from a plot of in D_{eff} versus m/P. The slope of the line is $-E_a$ and the intercept is in D_0 (Xiao *et al*., 2010).

Results and discussion

The effect of power level on the amount of humidity fish samples at different times is shown in Fig. (1).

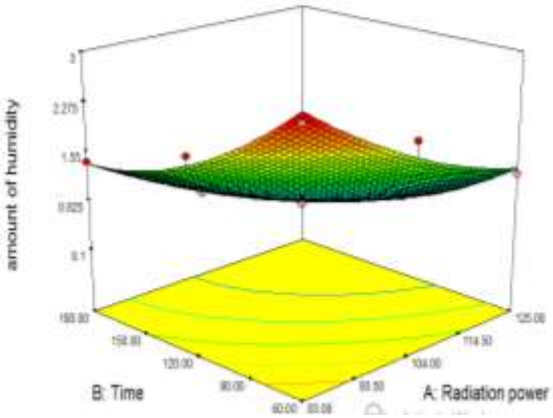

Fig. 1. Three-dimensional shape of the effect of input variables (time and radiation power) on the moisture content of fillet dried of common carp

The drying curves are similar to other foods. The drying curves show that infrared power levels affect the drying rate as expected. Figure 1shows how the moisture content decreased with drying time and was faster at higher power. As expected at higher infrared power, the higher heat absorption resulted in higher product temperatures, higher mass transfer driving force and faster drying rates with less drying time. In the case of infrared drying, the infrared energy can penetrate a finite depth of the product and convert into heat, so the water transfer is enhanced for infrared method (Riadh, Ahmad, Marhaban, & Soh, 2015).

Fig. (2) shows that significant differences in drying rate were found using infrared method. At the beginning when the moisture content was high, the drying rate under all drying conditions increased with time corresponding to a transition period where non-isothermal conditions existed, but then decreased continuously as the moisture content was reduced.

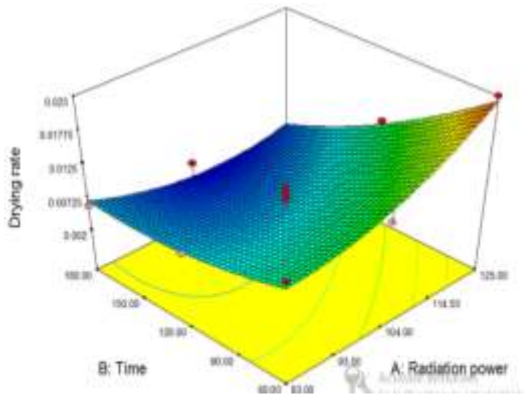

Fig. 2. Three-dimensional shape of the effect of input variables (time and radiation power) on the drying rate of fillet dried of common carp

This suggests that diffusion is the dominant physical mechanism governing moisture movements in the fish samples. Similar results were obtained by Darvishi *et al*. (2013). The results show that there was an approximate three-fold increase in drying rate at the start of the drying process when the infrared power level was increased from 83 to 125 W.

In order to select the best model to measure the effect of infrared radiation on the amount of moisture (Table 1), the analysis of variance was used. Given that the p-value level is less than 0.05 (P<0.05), the designed model is a suitable model for this measurement. Moisture level is an important parameter in sea food processing. It indicates the amount of water evaporated from the sample when subjected to any form of heat. The regression equation which describes the effects of drying process variables on moisture content in terms of actual values of the variable is given in: $Y=+0.88-0.73A-0.69B+0.22A^2+0.36B^2$. The linear positive terms indicated that moisture level in the fish increased with increase in temperature and drying time. The presence of positive interaction terms between temperature and drying time indicated that increase in their levels increased moisture content of the product. Green & Perry (2007) reported that drying period during which the instantaneous drying rate continually decreased which was referred to as falling rate period and that the falling rate is affected by drying temperature, etc.

Table 1. Analysis of variance of factors affecting the drying process of common carp fillets

Source	df	Average of squares		
		Moisture	Drying rate	Effective moisture diffusivity
Model	5	1.38**	6.063E-005**	6.883E-015**
A-Radiation	1	3.18**	2.817E-005*	8.893E-015**
B-Time	1	2.90**	1.815E-004**	4.873E-015**
AB	1	0.046^{ns}	4.900E-005*	-
A^2	1	0.14*	2.024E-005**	-
B^2	1	0.37**	8.047E-006^{ns}	-
Residual	7	0.021	4.235E-006	-
Lack of Fit	3	0.040^{ns}	4.148E-006^{ns}	6.09^{ns}
Pure Error	4	6.850E-003	4.300E-006	9.200E-018

Conclusions

It was concluded from this study that the solution temperature and drying time were the most pronounced factors affecting moisture content of common carp during infrared drying process. Response surface methodology was effective in optimizing the drying process parameters for the drying process of the fillets of common carp by infrared. The analysis of variance has it that the effects of the drying process variables were statistically significant. Conformation of the experimental results with the empirical model was evaluated using correlation coefficient (R^2) which was found for the proposed model as, $R^2 = 0.964$.

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