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Infrared Assisted Microwave Cooking of Atlantic Salmon (*Salmo salar*)

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Abstract

In this study, infrared–microwave combination heating was used to cook Atlantic salmon (*Salmo salar*) samples, and the optimum cooking conditions in infrared-microwave combination oven were determined. Response Surface Methodology (RSM) was used to identify optimum values of cooking time (4, 5, 6 minutes), halogen lamp power level (80%, 90%, 100%), and microwave power level (20%, 30%, 40%) regarding of four responses – internal temperature, cooking yield, L* and b* values. A three-factors modified Box–Behnken design was carried out to estimate the model coefficients. The derived second-order polynomial models sufficiently represented the experimental data. Optimum conditions were predicted as 5 minutes of cooking time, 100% halogen lamp power level, and 30% microwave power level by using the target values obtained in conventional cooking (at 200°C for 15 minutes). This study showed that infrared assisted microwave cooking is a promising alternative method for fish and other seafoods with reduced cooking time and color formation on the surface of salmon.

Keywords: Fish**,** infrared heating, microwave heating, optimization.

Atlantik Somon Balığı'nın (*Salmo salar*) Kızılötesi Destekli Mikrodalga ile Pişirilmesi

Özet

Bu çalışmada Atlantik somon (*Salmo salar*) örneklerinin pişirilmesinde kızılötesi–mikrodalga ısıtma kombinasyonu kullanılmış ve kızılötesi–mikrodalga kombinasyonu fırında optimum pişirme koşulları belirlenmiştir. Pişirme süresi (4, 5, 6 dakika), halojen lamba gücü (%80, %90, %100), ve mikrodalga gücünün (%20, %30, %40)] dört yanıta göre [iç sıcaklık, pişme verimi, renk (L* ve b* değerleri)] optimum değerlerini belirlemek için Yanıt Yüzey Yöntemi (RSM) kullanılmıştır. Model katsayılarını belirlemek için üç faktörlü Box-Behnken tasarımı kullanılmıştır. Elde edilen ikinci dereceden polinom modelleri deneysel verileri yeterli düzeyde temsil etmiştir. Geleneksel pişirme yönteminde (200°C'de 15 dakika) elde edilen hedef değerler kullanılarak, optimum koşullar 5 dakika pişirme süresi, %100 halojen lamba gücü ve %30 mikrodalga gücü olarak belirlenmiştir. Bu çalışma, daha kısa pişirme süresi ve somon yüzeyinde renk oluşumunun sağlanmasıyla kızılötesi-mikrodalga kombinasyonunun balık ve diğer deniz ürünleri için yüksek potansiyele sahip alternatif bir pişirme yöntemi olduğunu göstermiştir.

Anahtar Kelimeler: Balık**,** kızılötesi ısıtma, mikrodalga ısıtma, optimizasyon.

Introduction

Fatty fish such as salmon have nutritional benefits, especially because of their relatively high omega-3 fatty acid content. They contain two kinds of omega-3 long chain polyunsaturated fatty acids (LCPUFAs): eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Fatty fish are considered as a healthy choice in human diet since omega-3 fatty acids (EPA in particular) have beneficial effects on cardiovascular health by lowering cholesterol levels and blood pressure (Horrocks and Yeo, 1999; Kris-Etherton *et al*., 2002). Since humans cannot synthesize omega-3 fatty acids and LCPUFA contents of fatty fish are significantly higher than that of terrestrial animals, it is highly recommended to include fatty fish in the diet (Larsen *et al*., 2010).

In the last decade, the effects of different heating/cooking methods (e.g. deep frying, pan frying, boiling, grilling, oven baking/cooking, steaming, and microwave cooking) on nutritional value (i.e. proximate composition, fatty acid profile, vitamin and mineral contents) and quality attributes

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(i.e. texture, color, sensory evaluation) of different fish species including various species of salmon have been investigated by various researchers (Sahin and Sumnu, 2001; Al-Saghir *et al*., 2004; Gokoglu *et al*., 2004; Ersoy *et al*., 2006; Kong *et al*., 2007a, 2007b; Turkkan *et al*., 2008; Weber *et al*., 2008; Ersoy and Özeren, 2009; Mahmoud *et al*., 2009; Naseri *et al*., 2010; Stephen *et al*., 2010; Larsen *et al*., 2010, 2011; Ersoy, 2011). According to some researchers (Sahin and Sumnu, 2001; Turkkan *et al*., 2008; Mahmoud *et al*., 2009; Larsen *et al*., 2010; Stephen *et al*., 2010; Ersoy, 2011), microwave cooking is a promising cooking method for seafoods providing higher or comparable nutritional value as compared to raw material especially in terms of omega-3 fatty acids and lower cooking time (as compared to other cooking methods such as deep frying, baking and broiling). On the other hand, in some of the studies, microwave cooking was found to affect fatty acid composition of silver carp (Naseri *et al*., 2010), silver catfish fillets (Weber *et al*., 2008), or microwave-cooked King salmon was least liked by sensory panelists (Larsen *et al*., 2011). Different results obtained in different studies may be because of the differences of fish species, sampling, and selection of microwave cooking conditions. One of the drawbacks of microwave heating that adversely affects product acceptance by the consumer is the lack of desired color formation on the surface of food products. In recent years, combination heating techniques have been applied to solve this problem such as impingement-microwave combination heating and IR-MW (infrared-microwave) combination heating.

Combination heating implies the use of two different heating mechanisms together. The main purpose of using infrared heating in the same cavity with the microwave heating is to assist microwave heating in terms of reaching a more homogeneous temperature distribution on the target food and drying up the accumulated moisture due to the pressure driven moisture flow (Ni *et al*., 1999). Infrared radiation lies between the visible light and radio waves in electromagnetic spectrum, and it is divided into three categories: near-infrared radiation, mid-infrared radiation, and far-infrared radiation (Ranjan *et al*., 2002). In IR-MW combination cooking, infrared heating provides near-infrared radiation with low penetration depth which focuses on the surface of the product resulting in removal of surface moisture and formation of color on the surface, while microwave heating provides rapid processing resulting in significant reduction in cooking time.

Infrared-microwave combination heating has been used by different researchers for different food processing operations: Datta and Ni (2002) analyzed infrared and hot-air-assisted microwave heating of foods. Tireki *et al*. (2006) and Wang and Sheng (2006) used infrared-assisted microwave heating for drying of different foods. IR-MW combination baking was studied by a group of researchers, and 50-79% reduction in baking time compared to conventional baking was obtained (Demirekler *et al*., 2004; Keskin *et al*., 2004; Keskin *et al*., 2005; Sevimli *et al*., 2005; Sakiyan *et al*., 2007; Turabi *et al*., 2008). Seyhun *et al*. (2009) used infrared assisted microwave heating for tempering of frozen foods. Uysal *et al*. (2009) roasted hazelnuts by using IR-MW combination. There is no study on using IR-MW combination heating for cooking of fish and other seafoods, and when the results of the previous studies are considered, IR-MW combination cooking was expected to be a promising faster alternative cooking method for seafoods.

Response surface methodology (RSM) is a collection of mathematical and statistical techniques based on fitting a polynomial equation to the experimental data. The objective is to optimize a *response* (output variable), which is influenced by several *independent variables* (input variables), with a careful design of experiments. An experiment is a series of tests, called *runs*, in which changes are made in the input variables in order to identify the reasons for changes in the output response (Alvarez, 2000). The reason for choosing Box-Behnken design among other response surface designs (e.g. full factorial design, central composite design) is its advantage in requiring less number of runs. The aim of this study was to investigate the effects of infrared assisted microwave cooking on Atlantic salmon (*Salmo salar*) samples and to determine the optimum cooking conditions by varying infrared and microwave power levels and cooking time.

Materials and Methods

Materials

Atlantic salmon (*Salmo salar*) caught in Norwegian Sea was used for the experiments. Salmon fillets were bought from a market (Metro, Turkey) in Kocaeli, Turkey. The salmon fillets were cut into 10 × 6 × 1.2 cm pieces, and all samples were taken from the same section (i.e. between lateral line and dorsal fin) of the fish. Average weight of the samples was 85±2 g.

Experimental Design and Analysis

Response surface methodology (RSM) was applied to identify the optimum values of three variables: halogen lamp power level, microwave power level and cooking time, regarding of four responses – internal temperature, cooking yield and color (L* value and b* value). A modified Box–Behnken design with three-factors was selected to observe the effects on four responses at three levels. The design consisted of 15 runs, and it was performed by Minitab 16 Statistical Software (Minitab Inc., State Collage, PA, USA) in order to study the main effects and interactions. The ranges of the independent variables and experimental design levels are listed in Table 1. The selected levels for each variable were chosen on the basis of preliminary experiments (unpublished results). The experiments were conducted in a random order to avoid any bias. Data were analyzed by multiple regressions through the least-square method.

A second-order polynomial equation was used to express the responses as a function of the independent variables as follows:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i \chi_i + \sum_{i=1}^{k} \beta_{ii} \chi_i^{\,2} + \sum_{i=1}^{k} \sum_{j=i+1}^{k} \beta_{ij} \chi_i \chi_j \qquad (1)$$

where Y represents the predicted response, β_0 is the constant coefficient, k is the number of independent variables, χ_i and χ_j are the levels of the coded independent variables, and β_i, β_{ii} and β_{ij} are the linear, quadratic and interactive coefficients, respectively. Minitab 16 Statistical Software was used to optimize the responses, to estimate the coefficient parameters, and to obtain the 2-D contour plots of the response models.

Methods

Infrared Assisted Microwave Cooking

An infrared-microwave combination oven (Advantium oven™, General Electric Company, Louisville, KY, USA) was used for cooking of Atlantic salmon. The halogen lamps inside the oven provide near-infrared radiation (Keskin *et al*., 2004). There are three 1500 W halogen lamps inside the oven: Two of them are placed above the oven cavity and one at the bottom. The intensity of infrared heating can be modified by adjusting the power level of halogen lamps from 0% to 100%. The oven can also be used as a microwave oven, and the microwave power level can be adjusted from 0% to 100%. The power of microwave oven was determined as 738.5 W by IMPI 2-Liter test (Buffler, 1993). Three samples were placed into a glass cooking pan lined with waxy paper, and were cooked together for each run.

Conventional Cooking

As a control, the samples were cooked in an electrical conventional oven (Arzum, Turkey) at 200°C for 15 minutes. Three samples placed into the glass cooking pan lined with waxy paper were cooked together in the conventional oven.

Measurement of Temperature

The internal temperatures of salmon samples were measured by using a FISO real time measurement system (FISO Technologies Inc., Quebec, Canada) and the fiber optic temperature probe was placed to the center point of the samples just after cooking.

Calculation of Cooking Yield

All the samples were weighed before cooking (i.e. initial weight) and after cooking when they had reached room temperature (i.e. final weight), and the cooking yield (%) was calculated by the following formula: ((final weight / initial weight) × 100).

Measurement of Color

The color of the samples was measured with Minolta Color Reader (Minolta CR-400, Osaka, Japan). CIE L*, a*, b* color scale was used for color measurements. Two color values of CIE measurement system (L* and b*) were taken into consideration. The L* value represents ‘lightness’, from 0 (black) to 100 (white). The b* value represents ‘yellowness’ or ‘blueness’ ranging from +60 to -60. Triplicate readings were carried out from different points on the cooked salmon surfaces, and the mean value was calculated. Three replications were done for each sample.

Results and Discussion

Fitting of the Model

The experimental data yielded second-order polynomial equations as expected, and the coefficients of the equations were calculated by using the experimental data. The response surface regression and models were expressed in terms of coded variables, neglecting the statistically non-significant terms at 95% confidence level. In other words, the non-significant ($P>0.05$) model terms were excluded to simplify the equations. The resultant second-order polynomial models given in Table 2 sufficiently represented the experimental data with the coefficient of multiple determination (R^2) of 97.4%, 99.2%, 95.7% and 93.4% for the responses of internal temperature, cooking yield, L* value and b* value, respectively.

Response Surfaces of Dependent Variables

Model equations presented in Table 2 showed that all dependent variables (internal temperature, cooking yield and color (L* value and b* value)) significantly changed with halogen lamp power level (%), microwave power level (%), and cooking time.

To determine the significance of the regression coefficients of the independent variables, the Student’s ‘t’ test and the p-value were also used. The larger the magnitude of t and smaller the value of p, the more significant is the corresponding coefficient term. The microwave power level and cooking time were found to have the largest effect on all the dependent variables. Figures 1-4 show the contour

Table 1. Variables and coded levels for the Box-Behnken design

	Levels		
	-1	0	+1
Independent variables			
Halogen lamp power level (%) (X_1)	80	90	100
Microwave power level (%) (X_2)	20	30	40
Cooking time (minutes) (X_3)	4	5	6
Dependent variables			
Internal temperature (°C) (Y_1)			
Cooking yield (%) (Y_2)			
L* value (Y_3)			
b* value (Y_4)			

Table 2. Regression equations for cooked salmon in IR-MW combination oven

Quality Parameter	Equation	R^2	R^2_{adj}
Internal Temp. (ºC)	$Y_1 = 73.667 + 3.501^a X_1 + 6.416^b X_2 + 6.625^b X_3 - 3.332^c X_3^2 - 4.500^a X_1 X_3 + 4.750^a X_2 X_3$	97.4%	92.6%
Cooking Yield (%)	$Y_2 = 83.903 - 1.411^d X_1 - 2.595^d X_2 - 2.834^d X_3 - 1.092^a X_1^2$	99.2%	97.7%
L* value	$Y_3 = 72.593 - 1.004^c X_1 - 2.402^b X_2 - 1.989^a X_3 + 2.035^a X_1 X_3 - 1.558^c X_2 X_3$	95.7%	88.0%
b* value	$Y_4 = 26.377 + 1.504^c X_1 + 3.404^a X_2 + 2.570^a X_3 + 2.502^c X_2 X_3$	93.4%	81.5%

^{a} : Significant at 1% level, ^{b} : Significant at 0.1% level, ^{c} : Significant at 5% level, ^{d} : Significant at 0.01% level.

plots of the effects of the interaction between microwave power level and cooking time on the dependent variables at the fixed halogen lamp power level of 90%. Halogen lamp power level was used as the hold value for 2-D contour plots since it has the least effect.

Internal temperature (Figure 1) and b* value (Figure 2) increased with increasing microwave power level and cooking time, which revealed that higher microwave power level and longer cooking time was favorable for a higher internal temperature and b* value. However, cooking yield and L* value was inversely affected by the independent variables (Table 2). This indicated that cooking yield (Figure 3) and L* value (Figure 4) decreased with increasing microwave power level and cooking time. Lower microwave power level and shorter cooking time resulted in better cooking yield as expected. The decrease in L* value represents darker color of salmon due to the formation of brown pigments through Maillard reactions and the increase in b* value represents the increase in the yellowish color (Uysal *et al*., 2009). The higher the microwave power level and longer the cooking time, the lower the L* value, which was due to Maillard reactions.

The increase in internal temperature with increasing microwave power level was because of higher heat generation inside the samples. Moreover, higher internal heat generation related to microwave heating causes higher moisture vapor generation. In combination heating, with the help of infrared heating, moisture is removed from the surfaces of samples in shorter time since near infrared heating provides lower penetration depth resulting in heat focusing at the surface of the samples and increase in surface temperature ending up with color formation, especially increase in b* values and decrease in L* values. Similarly, increase in cooking time means samples were subjected to more microwave energy resulting in more heat generation and higher internal temperatures and b* values. During cooking, it was observed that, besides moisture removal, fat of the samples were also removed. As mentioned previously, removal of moisture from the sample is due to heat generation that creates significant interior pressure and concentration gradients resulting in higher rates of moisture losses (Datta, 1990). This heat generation may also cause porous structure providing removal of fat in melted form from those pores easily. Therefore, as microwave power increases, heat generation also increases, resulting in increase in removal of moisture and fat and decrease in cooking yield. Similarly, increase in cooking time means samples are subjected to more microwave energy resulting in more heat generation and decrease in cooking yield and L* values.

Response Optimization

Response optimization tool of Minitab 16 Statistical Software was performed to determine the optimum cooking conditions of Atlantic salmon. The minimum internal temperature of salmon was set to 70ºC according to AOAC 976.16 (Official method for cooking seafood products), and the target internal temperature was chosen as 75°C since cooking food until the core temperature is 75°C or above will ensure that the harmful bacteria are destroyed (CookSafe, 2005). The cooking time for conventional cooking was also chosen by preliminary experiments according to this criterion. Target values for cooking yield and color dimensions (L* and b* values) were determined according to the results obtained during conventional cooking (at 200°C for 15 minutes) of

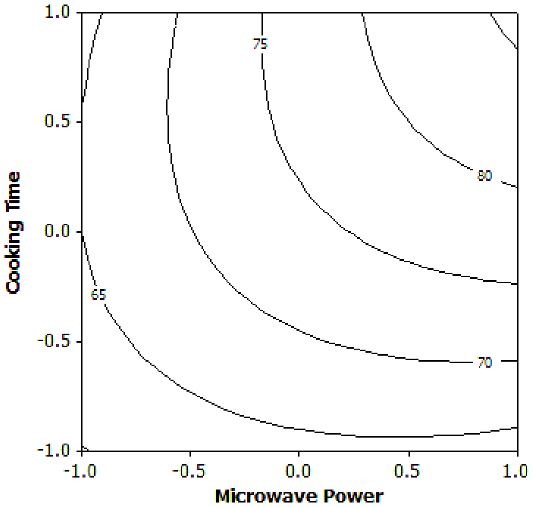

Figure 1. Response surface for internal temperature (ºC) in function of cooking time and microwave power level at a fixed halogen lamp power level of 90%. Hold value in coded level 0.

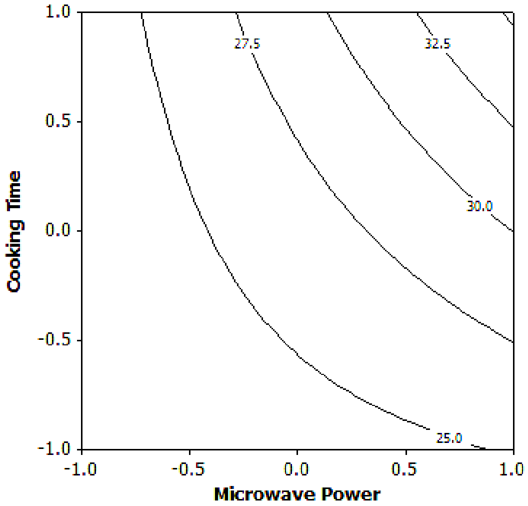

Figure 2. Response surface for cooking yield (%) in function of cooking time and microwave power level at a fixed halogen lamp power level of 90%. Hold value in coded level 0.

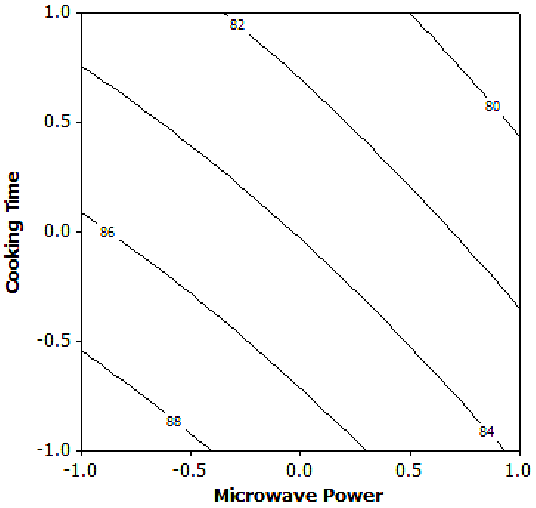

Figure 3. Response surface for L* value in function of cooking time and microwave power level at a fixed halogen lamp power level of 90%. Hold value in coded level 0.

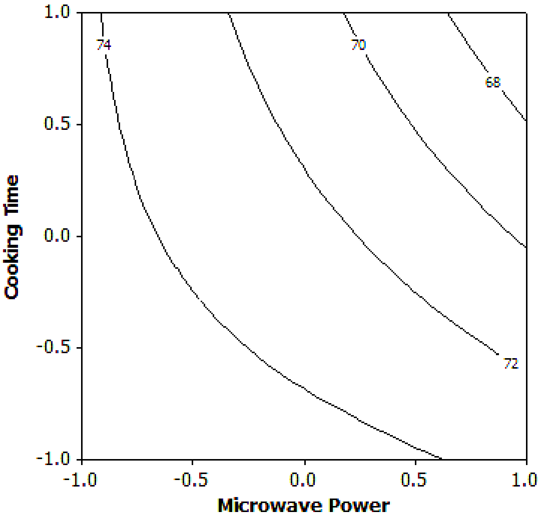

Figure 4. Response surface for b* value in function of cooking time and microwave power level at a fixed halogen lamp power level of 90%. Hold value in coded level 0.

Atlantic salmon. The optimum point was found to be 1.0000 for X_1, -0.3793 for X_2, 0.5180 for X_3. These values were rounded and corresponding uncoded values were found as 5 minutes of cooking time, 100% halogen lamp power level, and 30% microwave power level. The response values calculated at these optimum values are shown in Table 3. In order to make a comparison, the responses measured for conventionally cooked Atlantic salmon are also given in Table 3. As can be seen from Table 3, Atlantic salmon cooked in IR-MW combination oven at optimum conditions had comparable quality in terms of internal temperature, cooking yield and color (L* value and b* value) with conventionally cooked ones. Moreover, cooking time of the Atlantic salmon samples was reduced by 67%. Also, the composite desirability of the observed optimum factors for this study was obtained as 0.881489. The composite desirability is a single measure combining the individual desirability of all responses. When the aim is to target a response, the desirability is 1 at the target and decreases if the response deviates from the target in either direction (Tan *et al*., 2012).

Conclusion

The Atlantic salmon (*Salmo salar*) samples cooked with IR-MW combination oven had comparable quality with the ones cooked conventionally. In addition, the cooking time of the Atlantic salmon was significantly reduced. RSM was successfully applied for the optimization of processing conditions during IR-MW combination cooking of Atlantic salmon samples. The halogen

Table 3. Response values for Atlantic salmon cooked in IR-MW combination oven and control samples cooked in conventional oven

Response	Infrared-microwave combination oven cooking at the optimum conditions (100% IR - 30% MW - 5 min)	Conventional oven cooking (200˚C - 15 min)
Internal Temperature, ˚C (Y_1)	76.67	75.00
Cooking Yield, % (Y_2)	79.60	80.00
L* value (Y_3)	73.67	73.00
b* value (Y_4)	23.12	25.00

lamp power level (%), microwave power level (%) and cooking time were found to be the significant factors affecting the internal temperature, cooking yield and the color (L* and b* values) of the samples. This study showed that, considering the reduced cooking time and color formation on the surface of Atlantic salmon, IR-MW combination cooking is a promising alternative method for cooking fish and other seafoods.

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