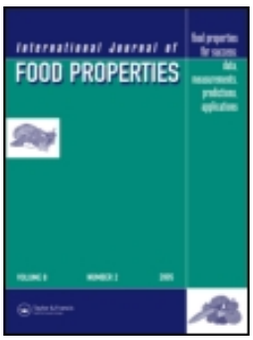

International Journal of Food Properties

ISSN: 1094-2912 (Print) 1532-2386 (Online) Journal homepage: https://www.tandfonline.com/loi/ljfp20

Steam Assisted Hybrid Cooking Behavior of *Semitendinosus* Muscle: Heterocyclic Amines Formation, Soluble Protein Degradation, Fat Retention, Surface Color, and Cooking Value

Hilal Isleroglu, Tansel Kemerlı-Kalbaran, Özgül Özdestan-Ocak, Ali Üren & Figen Kaymak-Ertekin

To cite this article: Hilal Isleroglu, Tansel Kemerlı-Kalbaran, Özgül Özdestan-Ocak, Ali Üren & Figen Kaymak-Ertekin (2016) Steam Assisted Hybrid Cooking Behavior of *Semitendinosus* Muscle: Heterocyclic Amines Formation, Soluble Protein Degradation, Fat Retention, Surface Color, and Cooking Value, International Journal of Food Properties, 19:5, 1139-1153, DOI: 10.1080/10942912.2015.1058276

To link to this article: https://doi.org/10.1080/10942912.2015.1058276

Published online: 28 Jan 2016.

International Journal of Food Properties, 19:1139–1153, 2016

ISSN: 1094-2912 print/1532-2386 online
DOI: 10.1080/10942912.2015.1058276

Taylor & Francis
Taylor & Francis Group

Steam Assisted Hybrid Cooking Behavior of *Semitendinosus* Muscle: Heterocyclic Amines Formation, Soluble Protein Degradation, Fat Retention, Surface Color, and Cooking Value

Hilal Isleroglu[1], Tansel Kemerlı-Kalbaran[2], Özgül Özdestan-Ocak[3], Ali Üren[4], and Figen Kaymak-Ertekin[3]

[1]*Gaziosmanpaşa University, Faculty of Natural Sciences and Engineering, Food Engineering Department, Tasliciftlik-Tokat, Turkey*
[2]*Gebze Institute of High Technology, Faculty of Engineering, Chemical Engineering Department, Kocaeli, Turkey*
[3]*Ege University, Faculty of Engineering, Food Engineering Department, Bornova-Izmir, Turkey*
[4]*Artvin Coruh University, Faculty of Medical Sciences, Nutrition and Dietetics, Artvin, Turkey*

Beef (*Semitendinosus* muscle) was cooked in natural convection, forced convection and steam assisted hybrid oven and saturated steam oven at different oven temperatures until the geometric center of samples reached different end temperatures. Heterocyclic amine (HCA) compounds formation, soluble protein degradation kinetics, cook value, changes in fat content, surface colour and overall acceptance of cooked beef were determined. Soluble protein degradation of beef was considered as first order reaction kinetics and the reaction rate constants, k, were determined in the range of 0.014-0.052 min^{-1}. In steam assisted hybrid oven had higher reaction rate constants compared to that of the convection ovens. The effect of cooking temperature on soluble protein degradation for natural convection, forced convection and steam assisted hybrid oven followed the Arrhenius type of equation with activation energies of 12.45, 14.57 and 60.16 kJ/mol, respectively. Lower HCAs contents, shorter cooking times, lower cook values and lower fat retention were obtained by steam assisted hybrid oven cooking. Steam assisted hybrid cooking could be considered as an alternative cooking method to obtain a healthier product without compromising the eating habits of conventional methods due to better appearance (moderate burned surface) than saturated steam oven samples and a product retaining the most of the nutritional values.

Keywords: Steam-assisted hybrid oven, Heterocyclic amine, Soluble protein, Kinetic modelling, Cook value.

Received 20 February 2015; accepted 1 June 2015.
Address correspondence to Hilal Isleroglu, Food Engineering Department, Faculty of Natural Sciences and Engineering, Gaziosmanpasa University, Vali Zekai Gumusdis St., 60150, Tasliciftlik-Tokat, Turkey. E-mail: hilal.isleroglu@gop.edu.tr
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ljfp.

INTRODUCTION

Cooking process provides many positive effects on meat quality such as taste and flavor enhancement, digestibility improvement, microbiological safety, and shelf life increase.[1] Oven cooking is one of the most preferred cooking operation of meat and forced convective oven cooking, the most common oven cooking system, generally results in desirable food quality traits.[2] However, in recent years, according to the consumers' preference through healthier foods, steam cooking, offering lots of benefits such as fast cooking times, optimum retention of vitamins, nutrients, flavor, color, and texture has become popular.[3,4] However, meat cooked by steam appears quite pale due to lack of caramelization and may need to be browned such as in a conventional oven. This drawback results in an extra step and extra time added to the cooking process. Some ovens named as combi or hybrid ovens combine steam with convection cooking and give the operator multiple cooking choices in a single piece of equipment and also these ovens were reported to improve flavor, taste, and texture of meat products.[5,6]

The effect of steam on cooking parameters (cooking yield and surface temperature) and texture, color, and sensory properties (juiciness, tenderness, and palatability) of the cooked meat has not yet been clearly explained. Published data about the use of steam convection hybrid ovens and their effects on the quality of the food products are limited and contradictory.[2,7,8] Murphy et al.[5] previously reported that the heat flux is closely related to the relative humidity (RH) of the oven air and results in different meat heating profile. The heating profile affects the extent of meat protein denaturation in the cooking process and consequently, the physical and sensory properties of the final product. Mora et al.[9] also reported that low steam cooking conditions (RH = 35%) resulted in higher quality cooked turkey meat, increasing cooking yield and tenderness due to slow cooking rate.

The high-temperature cooking of meats is known to produce heterocyclic amine compounds (HCAs), reaction products of creatine with amino acids and carbohydrates which are naturally existent compounds in muscle tissues, that have been shown to be mutagenic[10,11] and carcinogenic.-[12–15] It has been proposed that HCAs, potent mutagens present at μg/kg levels in cooked foods, play an important role in the aetiology of human cancer.[16] The presence of HCAs in cooked foods has become a major concern for consumers. Several case-control studies have reported positive associations between higher consumption of well-done cooked red meat and risk of colon cancer, breast cancer, lung cancer, and gastric cancer.[17] HCAs mainly found in cooked meat and fish products are 2-amino-3-methylimidazo[4,5-f]quinoline (IQ), 2-amino-3,4-dimethylimidazo[4,5-f]quinoline (MeIQ), 2-amino-3,8-dimethylimidazo[4,5-f]quinoxaline (MeIQx), 2-amino-3,4,8-trimethylimidazo[4,5-f]quinoxaline (4,8-DiMeIQx), and 2-amino-1-methyl-6-phenylimidazo[4,5-b]pyridine (PhIP).[18] HCAs formation during cooking depends on the type of meat, the temperature of the cooking surface, the degree of browning, and the length of cooking time. More HCAs are formed when heating medium temperatures are higher than 220°C such as frying or grilling. However, HCAs also formed at lower temperatures when the cooking time is too long, as in roasting.[19] Since HCAs formed by cooking process are mutagenic and carcinogenic, it is important to minimize their formation during cooking and, therefore, healthy cooking is getting more important in this respect.

The aim of this study was to determine the influence of different oven types, oven temperatures, and end point temperatures on the physico-chemical properties of beef during oven cooking. Accordingly, in this study, beef (*Semitendinosus* muscle) was cooked in natural and forced convection (FC) ovens, steam-assisted hybrid oven and SO at different oven temperatures until the samples geometric center reached different end-point temperatures. After cooking processes at each condition, the HCAs (IQ, MeIQx, 4,8-DiMeIQx, PhIP, norharman, and harman) formation during cooking process was determined as an indicator of harmfulness of the product. Decrease in soluble protein content of beef during cooking was used in determination of soluble protein degradation kinetics that was fitted with the first order reaction equation which is commonly used in the thermal degradation of organic compounds.

MATERIAL AND METHODS

Material

Semitendinosus muscles (n = 60 muscles) were purchased from Pınar Et A.S. (Izmir, Turkey) shortly after slaughter, and stored in vacuum bags at 4°C 24 h until cooking. Each muscle was divided into 2 parts (n = 120, number of samples) that was 70 mm thick. A total of ~350–400 g meat was used in each trial (one piece). Proximate composition and pH of each raw muscle was determined before cooking process. The total water content, 74.95 (±1.48 wet basis)% using gravimetric method at 105°C for 24 h, the total protein content, 20.42 (±0.60 wb)% by Kjeldahl method[20] and total fat content, 4.00 (±0.30 wb)% using chloroform-methanol method[21] were determined as an average. Total ash content was found 1.07 (±0.07 wb)% using gravimetric method and heating the sample at 550°C for 24 h.[20] The pH was measured using pH meter (Inolab pH 720-WTW) after homogenizing 10 g of the sample with 100 mL distilled water and the average pH value of raw meat was found 5.36 (±0.05).

Cooking

Cooking experiments were carried out in a steam assisted hybrid oven (STA; Arcelik, 9681 ESLTI), in a domestic use electrical convectional oven (Arcelik, KF 852 ESRI) and also in a SO (Arcelik, BF 840). STA used in this study is a hybrid oven with 48×43×25 cm dimensions having an inner steam generator mounted at the back panel of the oven. The steam generated from ~350 g water was injected into the oven cavity in five times consecutively during cooking, being started from 3rd min of cooking process. SO has not any heating resistance in the oven cabinet; it can only supply heat from saturated steam during cooking.

Two cooking trials for each treatment (n = 120, number of cooked samples; 60 for chemical analysis, 60 for sensorial analysis) were carried out by placing one piece of meat on a sieved tray located at the half height of the ovens. The meat samples were cooked at three different temperatures 180, 210, and 240°C in natural convection (NC, FC, and STAs. The meat sample was also cooked at 100°C in SO under saturated steam. All cooking experiments in ovens have started at constant initial uniform temperature of 10°C and cooking treatments at each temperature and oven type ended when meat samples reached three different end point temperatures, 65°C at its thermal center for medium-rare, 72°C for medium, and 80°C for medium-well. The temperature of each sample was measured in the geometric center of each slice using a type J-thermocouple with data logger (Testo, 177T4). After cooking, meat samples were allowed to reach the ambient temperature and used for analyses directly.

Determination of Degree of Cooking (Cook Value)

The degree of cooking at the thermal center of each sample was expressed in terms of cook value (C-value; Eq. 1). The C-value was obtained from the integration of the heat penetration curve where t is the time, T_{ref} is the reference temperature; set equal to 100°C, z is the temperature increase that induces a 10-fold increase of the reaction rate of the chemical reaction taken as reference; z was set at 33°C as previously reported by Holdsworth[22] and Poon et al.[23]

$$C^{z}_{T_{ref}} = \int_{0}^{t} 10^{\frac{T-T_{ref}}{z}} dt \tag{1}$$

Cook values were calculated taking into consideration only the heating phase not the total process that consisted of heating and cooling phases.

Determination of Soluble Protein

Soluble protein analysis of samples was carried out according to Bradford.[24] The amount of soluble protein in the sample was calculated according to a calibration curve prepared by albumin fraction V standard. Soluble protein contents were obtained for three aliquots of the same sample that underwent the whole analytical procedure.

HCA Analysis

HCAs contents of samples were determined by the method of Özdestan et al.[25] Samples were homogenized before the analyses. Four grams of the sample was homogenized in 25 mL 0.2 M HCl, suspension was taken into a 100 mL conical flask, and shaken for 1 h. The mixture was clarified by Carrez I and Carrez II solutions and filtered through a Whatman (40) filter paper. Then solid phase extraction (SPE) clean-up was applied to eliminate matrix interferences in the sample. An Accubond C_{18} SPE cartridge (3 cm^3/200 mg, Agilent Technologies, USA) and an Oasis MCX cartridge (3 cm^3/60 mg, Waters, Milford, Massachusetts, USA) were used consecutively to eliminate impurities. Chromatographic analyses of IQ, MeIQx and 4,8-DiMeIQx were realized by high-performance liquid chromatography (HPLC) equipped with a diode array detector (DAD). The chromatographic column was BDS Hypersil C_{18} (5 μm particle size, 150 mm × 4.6 mm i.d., Thermo Scientific). IQ was studied at 254 nm, MeIQx, and 4,8-DiMeIQx were measured at 263 nm. For PhIP, norharman, and harman, chromatographic analyses were accomplished by HPLC using a fluorescence detector operating at 340 and 420 nm as excitation and emission wavelengths, respectively. HCAs analyses were realized in duplicate.

Determination of Fat Retention

Total fat analysis of samples was carried out by modifying the method of Folch et al.[21] Ten grams of sample was homogenized with 100 mL of chloroform/methanol mixture (2/1 v/v). After dispersion the whole mixture was filtered through a folded filter paper and the solution was taken into a separating funnel. Following the addition of 20 mL 0.4% (w/v) $CaCl_2$ the mixture was shaken and equilibrated for 12 h at room temperature. The lower chloroform phase containing fats was taken into a rotary evaporator and chloroform was evaporated at 80ºC. The sample was dried to a constant weight in an oven at 105ºC. Total fat analyses were realized in duplicate. The fat retention was calculated according to Serdaroglu[26] is as follows:

$$\%\text{Fat retention} = \left[\frac{(\text{cooked weight}) \text{ x } (\%\text{fat in cooked meat})}{(\text{raw weight})\text{x}(\%\text{fat in raw meat})}\right] \quad (2)$$

Color Analysis

The color was measured on the surface of the cooked samples using a Minolta Colorimeter (Minolta, DP-400) as Commission Internationale de l'eclairage (CIE) Lab color parameters, L^* (lightness), a^* (redness), b^* (yellowness). The measurements were repeated at four randomly selected locations on each sample. The individual differences in L^*, a^*, and b^* values of each cooking treatments in respect of the color of the raw samples (r) were evaluated using ΔE according to Eq. (3).[27]

$$\Delta\text{E} = \sqrt{(L^* - L_r^*)^2 + \left(\text{a}^* - a_r^*\right)^2 + \left(b^* - b_r^*\right)^2} \quad (3)$$

Sensory Evaluation

The sensory tests were performed by a semi-trained panel of 10 people using 5-point (1 = dislike very much, 5 = like very much) hedonic scale that referred to degree of like or dislike.[28] The overall acceptance of samples was evaluated in terms of surface color, textural properties, and juiciness of samples. Two sessions per day were conducted in which four or five randomly three digits coded samples during session were evaluated in random order with 2 h break between sessions. Sensory analyses were carried out at daylight and at room temperature.

Data Analysis

The results were analyzed using SPSS 15.0 statistics package program (IBM Corp., New York, USA). The data were evaluated by one-way analysis of variance (ANOVA) with a Duncan significant difference test. Confidence level of $p < 0.05$ was applied to identify significant difference among the different cooking conditions. The mean absolute percentage deviation (% P) between the experimental and calculated values was calculated to validate the kinetic model as given by Isleroglu et al.[29]

RESULTS AND DISCUSSION

The cooking times of all samples to reach the desired internal temperatures in three different oven types (NC, FC, and STA) are shown in Table 1. The injection of steam in STA oven significantly reduced the cooking time compared to NC and FC ovens, as expected.[5,6] The shortest cooking time was obtained at samples cooked in STA, whereas the longest cooking times were obtained in FC oven for all oven temperatures. In STA, the steam injected to the oven chamber enabled to increase heat transfer coefficient of moist air and, therefore, the faster cooking was achieved. Additionally, the steam in the oven chamber hindered the formation of a thick crust layer on the surface of samples, and so the heat is conducted easier inside the samples and shortened the cooking time. Although the FC ovens have higher heat transfer coefficient compared to NC ovens,

TABLE 1
Cooking times (min) of beefs at different conditions

Cooking temperature (°C)	*Oven type*	*End point temperature (°C)*		
		65	*72*	*80*
180	NC	44.0 (±1.5)^{a,g}	52.5 (±1.5)^{a,g}	67.0 (±1.5)^{a,g}
	FC	49.3 (±2.3)^{a,h}	57.5 (±3.3)^{a,i}	70.3 (±4.0)^{a,i}
	STA	33.8 (±1.3)^{b,i}	38.0 (±1.5)^{b,j}	45.5 (±1.5)^{b,j}
210	NC	43.8 (±3.3)^{c,g}	50.8 (±3.3)^{c,gh}	60.8 (±3.3)^{c,g}
	FC	45.3 (±0.0)^{c,h}	53.0 (±0.3)^{c,i}	63.5 (±0.0)^{c,i}
	STA	33.0 (±0.0)^{d,i}	37.5 (±0.0)^{d,j}	44.5 (±0.0)^{d,j}
240	NC	35.8 (±2.3)^{ef,g}	41.0 (±2.5)^{ef,h}	48.0 (±2.5)^{ef,h}
	FC	40.8 (±1.0)^{e,h}	46.5 (±1.8)^{e,i}	54.8 (±2.5)^{e,i}
	STA	31.3 (±1.3)^{f,i}	35.5 (±1.8)^{f,j}	41.3 (±2.0)^{f,j}

NC: natural convection; FC: forced convection; STA: steam assisted hybrid oven;
All data are reported as means (±standard deviations) of two parallel measurements;
The different letters after the values in the same column indicate that the means is different significantly ($p < 0.05$);
First letters indicate difference between oven types in the same cooking temperature, second letters indicate difference between cooking temperatures in the same oven. None of the letters indicate comparison between the rows.

the cooking times in FC ovens were longer than those in NC ovens ($p > 0.05$). It might be attributed to the obstruction of heat conduction toward the inner parts of sample due to quick formation of thick crust layer on the surface of sample under forced convective condition. The cooking times of samples cooked in saturated SO were 24.3 (±2.8), 35.8 (±4.5), and 42.0 (±7.5) min for the end-point temperatures of 65, 72, and 80°C, respectively. Despite the low cooking temperature of 100°C in SO, it was observed that cooking times were rather short due to the increase of heat flux. The higher convective heat transfer coefficient of moist air and condensation of steam on the meat surface increased the heat flux in steam cooking and it resulted to be the fastest cooking with a 8–22% reduction compared to STA.

The cook values (C-value), as a measurement of the cumulative heat impact of time/temperature history on a food quality attribute, calculated for beef samples during oven cooking are shown in Fig. 1. The cook values of STA samples were lower than natural and forced convective cooked samples at all conditions, and this could be attributed to the presence of steam at the oven chamber as explained previously. The cook values were not significantly different between natural and FC ovens, while cook values of STA samples were significantly lower than other samples ($p < 0.05$). Similar results were obtained by Vittadini et al.[6] who calculated the cook values of meat for both center and surface positions for NC, FC, and FC+steam cooking treatments. It was found that the cook values of samples for center position cooked in convection+SO were smaller than cook values of samples cooked in natural and FC oven, significantly ($p < 0.05$).[6] The cook values of samples cooked in SO were rather low as 0.76, 1.51, and 3.43 min for the end point temperatures of 65, 72, and 80°C, respectively.

Cooking process causes heat-induced changes in protein solubility which affects the water holding capacity of meat. Because of the protein changes as a result of heating, moisture within the meat myofibrils in the narrow channels between the filaments changes as meat shrinks within the tissue matrix.[5] Figure 2 illustrates the total soluble protein content of beef samples at different cooking conditions. Total soluble protein content of samples decreased with increasing end point temperatures, cooking time, and also oven temperatures. In STA, samples having lower soluble protein content were obtained compared to the convection ovens at the same degree of cooking. The total soluble protein content of samples cooked in saturated SO was determined as 0.16 ± 0.01, 0.14 ± 0.01, and 0.12 ± 0.01% (w/w) for the end point temperatures of 65, 72, and 80°C, respectively. Although the cooking temperature was lower in SO, soluble protein contents of samples were obtained noticeably lower than other samples. These results asserted that fast cooking process and/or existence of steam could improve or change the denaturation form of soluble proteins. The low soluble protein content of STA samples in contravention of their low cook values indicated the effect of steam on protein denaturation pattern. However, in literature the effect of steam on quality parameters of meat has not been clearly explained.[9]

Soluble protein degradation in beef samples with cooking time was taken into account as a first order reaction kinetics. The reaction rate constant, k, was found to be in the range of 0.014–0.052 (min^{-1}) and increased with increasing cooking temperature within the same oven type (Table 2). The effect of cooking temperature on soluble protein degradation for NC, FC, and STA followed the Arrhenius type of equation with activation energies of 12.45, 14.57, and 60.16 kJ/mol, respectively. The Arrhenius plot of three oven types was illustrated in Fig. 3. The mean relative percentage deviation P (%) was found to be below 10% for all conditions and the model was considered acceptable. Murphy et al.[5] reported that soluble proteins might be used as an indicator for the degree of cooking. According to soluble protein content results, it might be concluded that it could be possible to reach same degree of cooking in a shorter cooking time by using STA.

The HCAs contents of samples, formed during oven cooking were determined in terms of IQ, MeIQx, and 4,8-DiMeIQx by using DAD and PhIP, norharman, and harman by using fluorescence detector. The limits of detection were calculated to give a signal-to-noise ratio of 3 and were found between 0.04 and 1.40 ng/g. LOD values were 1.25 ng/g for IQ, 0.86 ng/g for MeIQx, 1.40 ng/g for 4,8-DiMeIQx, 0.04 ng/g for PhIP, 0.65 ng/g for narharman, 0.26 ng/g for harman. The limits of

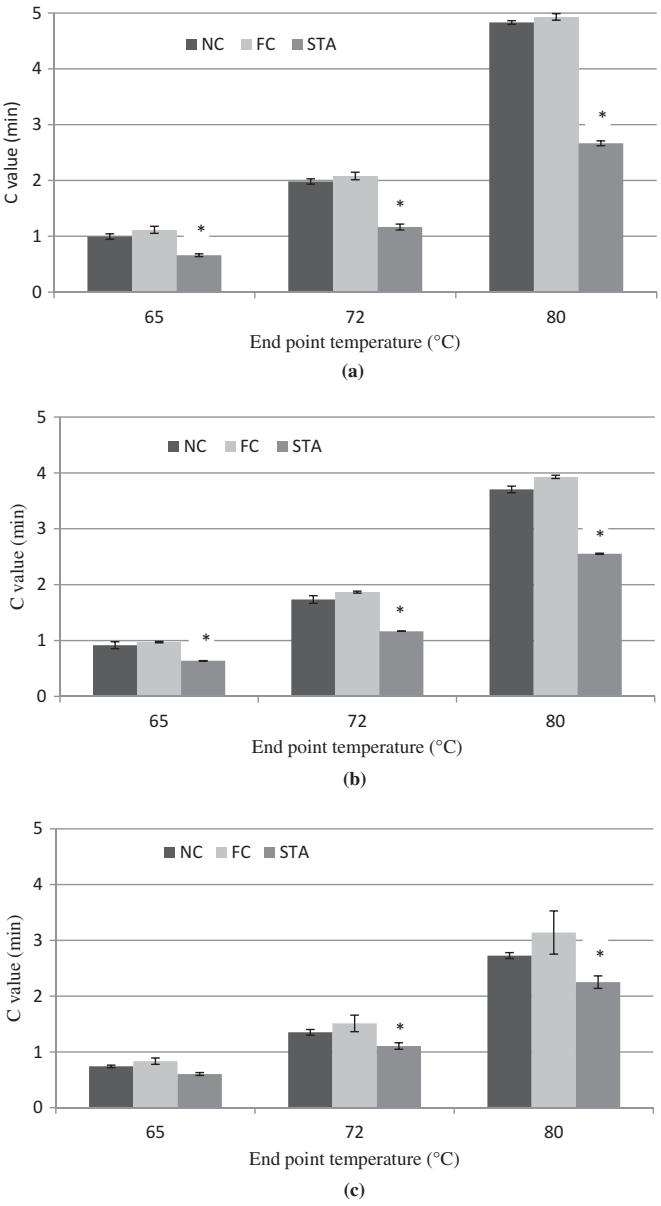

FIGURE 1 C-values of samples cooked at different conditions; (a) 180°C, (b) 210°C, (c) 240°C (NC: natural convection; FC: forced convection; STA: steam-assisted hybrid oven). Bars with an asterisk are significantly different ($p < 0.05$).

quantification (LOQ) were calculated to give a signal-to-noise ratio of 10 and were found in the range of 0.13–4.40 ng/g. LOQ values were 3.76 ng/g for IQ, 2.59 ng/g for MeIQx, 4.40 ng/g for 4,8-DiMeIQx, 0.13 ng/g for PhIP, 1.96 ng/g for narharman, 0.79 ng/g for harman. Recovery values were found as 73.9% for IQ, 87.8% for MeIQx, 68.9% for 4,8-DiMeIQx, 76.3% for PhIP, 85% for narharman, 87.7% for Harman.[25]

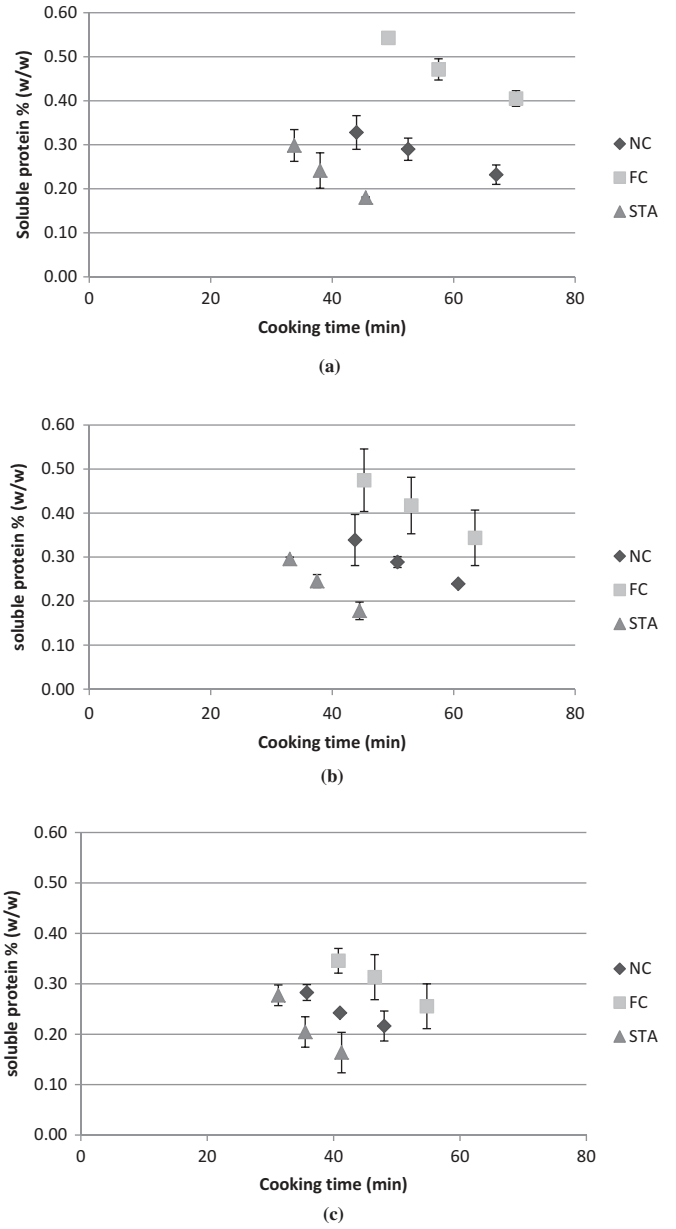

FIGURE 2 Soluble protein content (w/w) of samples cooked at different conditions, (a) 180°C, (b) 210°C, (c) 240°C (NC: natural convection; FC: forced convection; STA: steam-assisted hybrid oven).

The IQ, MeIQx, and 4,8-DiMeIQx were not found in any samples. The PhIP, norharman, and harman contents of samples were given in Table 3. As seen in Table 3, STA samples had lower HCAs content than NC and FC samples, whereas FC samples had the highest ones in all conditions. HCAs concentrations of FC beef samples, which were cooked at 210 and 240°C, were generally found higher than 50 ppb. The maximum total HCAs content was observed in FC

TABLE 2
Reaction rate constants (k, min^{-1}) for soluble protein degradation

Oven type	*Cooking temperature (°C)*	k *(min^{-1})*	R^2	*% P*
	180	0.015	1.000	1.74
NC	210	0.020	0.997	6.35
	240	0.022	0.972	4.48
	180	0.014	0.989	1.71
FC	210	0.018	0.999	0.75
	240	0.022	0.991	1.31
	180	0.043	0.996	2.30
STA	210	0.044	0.999	7.29
	240	0.052	0.970	5.03

NC: natural convection; FC: forced convection; STA: steam-assisted hybrid oven.

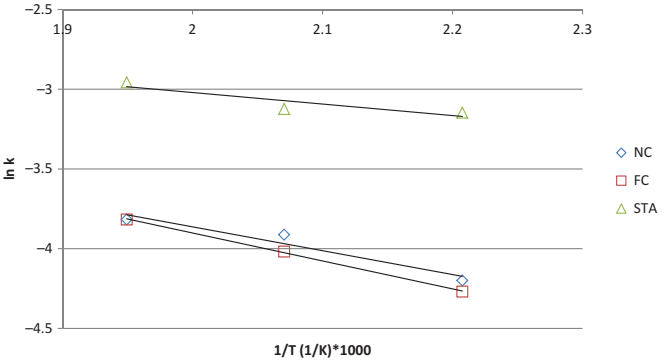

FIGURE 3 Arrhenius plot for soluble protein degradation (NC: natural convection; FC: forced convection; STA: steam-assisted hybrid oven).

samples cooked at 240°C to reach 65°C end-point temperature and HCAs concentrations decreased with increasing end-point temperature. These results were found in accordance with the results of Skog and Jagerstad.[30] In meat products, mutagenic activity increases during cooking time between 150 and 170ºC. HCA concentrations of meat products increase in the first minutes of cooking between 190 and 250ºC and then decrease or remain constant.[30] Total HCAs content of beef samples decreased with long cooking time especially at high temperatures. The reason for these results might be degradation of HCAs with long cooking time at high cooking temperatures in accordance with the results of Arvidsson et al.[31] In SO samples, none of HCAs was determined except harman (4.66 ± 2.39 ppb) and PhIP (0.66 ± 0.22 ppb) to reach 80°C end-point temperature.

In most cooked meat products, both MeIQx and PhIP were reported to occur more frequently than the other HCAs.[32–35] We didn't find MeIQx in our samples. PhIP was one of the most abundant HCAs in accordance with literature value. Contrary to expectations, HCAs levels were much lower in very well-done cooked samples. The formation of HCAs may be mostly dependent on the type of meat and cooking type. In addition, although comparison of HCA concentrations across published studies is informative, consideration should be given to differences between studies in food samples, cooking, and analytical methods.

TABLE 3
HCA contents (ppb) of NC, FC, STA samples at different oven temperatures

Oven temperature(°C)	*Oven type*	*End point temperature (°C)*								
		PhIP (ppb)			*Norharman (ppb)*			*Harman (ppb)*		
		65	*72*	*80*	*65*	*72*	*80*	*65*	*72*	*80*
180	NC	1.69 (±1.24)^{a,e}	6.36 (±4.23)^{a,f}	3.66 (±1.84)^{a,d}	ND	ND	ND	6.19 (±0.26)^{a,f}	6.21 (±0.61)^{a,e}	6.64 (±1.64)^{a,e}
	FC	7.94 (±2.94)^{a,g}	7.34 (±1.34)^{a,g}	2.73 (±2.07)^{a,e}	0.51 (±0.39)^{a,f}	13.91 (±1.91)^{a,d}	ND	8.93 (±1.93)^{a,g}	8.32 (±1.68)^{a,f}	ND
	STA	3.83 (±2.71)^{a,i}	0.39 (±0.91)^{a,i}	ND	ND	ND	ND	ND	ND	ND
210	NC	3.37 (±0.03)^{b,ef}	5.86 (±2.28)^{b,f}	0.47 (±0.47)^{b,d}	16.47 (±8.24)^{b,e}	ND	ND	5.51 (±1.01)^{b,f}	11.47 (±2.73)^{b,e}	6.20 (±0.37)^{b,e}
	FC	1.09 (±0.00)^{bc,g}	46.00 (±4.00)^{c,h}	ND	76.73 (±6.73)^{c,g}	4.58 (±0.42)^{b,e}	ND	28.84 (±6.16)^{c,g}	48.10 (±3.10)^{c,g}	6.67 (±0.47)^{b,f}
	STA	0.93 (±0.91)^{c,i}	0.43 (±0.03)^{b,i}	0.05 (±0.00)^{b,f}	ND	ND	ND	7.62 (±0.62)^{b,i}	9.96 (±1.51)^{b,h}	3.10 (±0.45)^{c}
240	NC	5.48 (±0.68)^{d,f}	1.16 (±0.10)^{d,f}	0.47 (±0.26)^{c,d}	ND	ND	ND	7.66 (±1.16)^{d,f}	6.55 (±1.55)^{d,e}	ND
	FC	95.55 (±29.45)^{e,h}	1.94 (±0.14)^{e,g}	ND	53.33 (±5.33)^{d,h}	3.97 (±1.53)^{c,e}	ND	84.46 (±13.54)^{e,h}	13.43 (±7.0)^{d,f}	3.15 (±0.14)^{d,g}
	STA	0.54 (±0.00)^{d,i}	ND	ND	ND	ND	ND	7.66 (±0.66)^{d,i}	3.28 (±0.28)^{d,i}	ND

NC: natural convection; FC: forced convection; STA: steam-assisted hybrid oven; ND: not determined;

All data are reported as means (±standard deviations) of two parallel measurements;

The different letters after the values in the same column indicate that the means is different significantly ($p < 0.05$);

First letters indicate difference between oven types in the same cooking temperature, second letters indicate difference between cooking temperatures in the same oven. None of the letters indicate comparison between the rows.

Figure 4 illustrates the fat retention (%) of beef samples at different cooking conditions. Cooking conditions affected the fat content, hence its retention in cooked samples. It was observed that the fat retention (%) values of samples varied in a range of 27–47% in NC, 34–55% in FC, and 30–40% in STA samples (Fig. 4). In steam-assisted hybrid cooking, the late formation of the crust

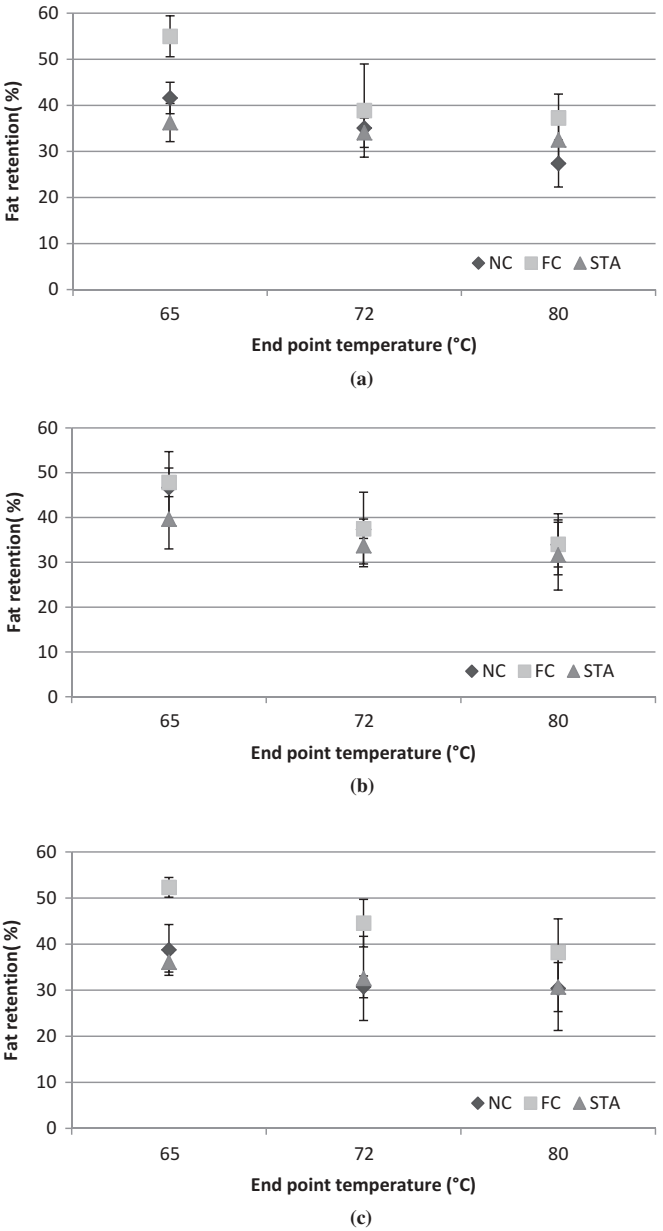

FIGURE 4 Fat retention (%) of samples cooked at different conditions, (a) 180°C, (b) 210°C, (c) 240°C (NC: natural convection; FC: forced convection; STA: steam-assisted hybrid oven).

TABLE 4
Crust color (L^*, a^*, b^*, ΔE) values of NC, FC, STA, and SO samples

		End point temperature (°C)											
		L*			a*			b*			⊿E		
Cooking temperature (°C)	Oven Type	65	72	80	65	72	80	65	72	80	65	72	80
100	SO	55.8 (±0.4)	53.7 (±0.2)	49.3 (±0.8)	6.6 (±0.0)	7.7 (±1.2)	8.3 (±0.6)	16.7 (±0.4)	16.8 (±0.3)	18.2 (±0.7)	17.1 (±0.4)	15.2 (±0.9)	13.5 (±0.4)
	NC	44.1 (±2.8)^{a,f}	40.0 (±4.6)^{ab,g}	37.0 (±3.0)^{ab,e}	10.9 (±0.7)^{a,f}	12.5(±0.4)^{a,g}	13.3(±0.2)^{a,h}	15.3 (±0.2)^{a,f}	14.4(±0.3)^{a,g}	15.3(±0.1)^{a,e}	9.7 (±0.5)^{a,d}	9.8 (±0.5)^{a,g}	11.4 (±0.1)^{a,d}
180	FC	39.5 (±1.5)^{a,h}	37.8 (±0.4)^{a,i}	34.9 (±1.3)^{a,f}	16.3 (±0.9)^{b,h}	16.4 (±0.4)^{b,hi}	16.7 (±0.3)^{b,j}	17.0 (±1.2)^{a,h}	14.9(±0.2)^{a,i}	13.0(±1.3)^{a,f}	8.9 (±0.7)^{a,f}	9.3 (±0.4)^{a,i}	11.6 (±1.2)^{a,e}
	STA	45.1 (±2.3)^{a,jk}	44.5 (±2.1)^{b,l}	41.1 (±1.0)^{b,h}	9.0 (±0.4)^{a,i}	9.3 (±0.2)^{c,j}	10.8 (±0.4)^{c,l}	14.7 (±0.0)^{a,j}	18.7(±0.1)^{b,k}	18.9(±0.4)^{b,g}	11.3 (±0.7)^{a,h}	12.5 (±0.1)^{b,l}	12.4 (±0.1)^{a,g}
	NC	44.6 (±2.0)^{b,f}	39.2 (±1.2)^{cd,g}	33.4 (±2.0)^{c,e}	10.8(±0.3)^{c,f}	13.2(±1.1)^{d,g}	15.1(±1.0)^{d,hi}	16.8 (±0.5)^{b,f}	17.5(±0.6)^{e,h}	12.9(±1.5)^{c,e}	10.3 (±0.2)^{b,de}	11.0 (±0.3)^{c,g}	13.5 (±2.1)^{b,d}
210	FC	34.4 (±1.0)^{c,hi}	33.8 (±0.4)^{c,j}	31.8 (±0.3)^{c,fg}	13.6 (±0.4)^{e,h}	17.2 (±0.1)^{e,h}	15.1 (±0.4)^{d,j}	14.1 (±0.4)^{c,hi}	13.1(±0.0)^{d,j}	13.0(±0.6)^{c,f}	13.3 (±0.7)^{b,fg}	12.5 (±0.4)^{c,j}	15.0 (±0.3)^{b,e}
	STA	47.0 (±2.6)^{b,j}	44.0 (±2.8)^{d,l}	33.3 (±2.0)^{c,h}	10.8 (±1.1)^{c,i}	12.4 (±0.4)^{d,k}	13.4 (±0.2)^{d,m}	18.6 (±0.4)^{b,k}	22.1(±1.4)^{e,k}	16.1(±1.2)^{c,g}	11.2 (±1.3)^{b,h}	12.7 (±0.4)^{d,l}	14.8 (±1.4)^{b,g}
	NC	35.4 (±0.7)^{de,g}	32.3 (±0.5)^{ef,h}	31.8 (±0.3)^{d,e}	14.3(±0.6)^{d,g}	15.0(±1.0)^{f,g}	16.7(±0.5)^{e,i}	11.8 (±0.7)^{d,g}	13.4(±0.1)^{f,g}	15.9(±0.0)^{d,e}	11.9 (±0.4)^{c,e}	14.5 (±0.6)^{e,h}	15.0 (±0.8)^{c,d}
240	FC	32.2 (±1.8)^{d,i}	31.0 (±0.2)^{e,k}	27.9 (±1.1)^{d,g}	14.1 (±0.5)^{d,h}	14.5 (±0.8)^{f,i}	10.8 (±0.6)^{f,k}	13.0 (±0.4)^{d,i}	15.0(±0.5)^{f,i}	11.6(±1.5)^{d,f}	15.00 (±1.8)^{c,g}	16.2 (±0.1)^{f,k}	20.2 (±1.3)^{c,f}
	STA	37.9 (±0.6)^{e,k}	36.6 (±2.0)^{f,l}	34.8 (±3.9)^{d,h}	14.2 (±0.0)^{d,j}	14.4 (±0.2)^{f,l}	14.5 (±0.1)^{g,m}	18.3 (±0.6)^{e,k}	16.8(±1.8)^{f,k}	16.8(±2.3)^{d,g}	11.7 (±0.1)^{c,h}	11.9 (±0.7)^{ef,l}	13.3 (±2.4)^{c,g}

NC: natural convection; FC: forced convection; STA: steam assisted hybrid oven; SO: steam oven;

All data are reported as means (±standard deviations) of two parallel measurements;

The different letters after the values in the same column indicate that the means is different significantly ($p < 0.05$);

First letters indicate difference between oven types in the same cooking temperature, second letters indicate difference between cooking temperatures in the same oven. None of the letters indicate comparison between the rows.

TABLE 5
Overall acceptance values of NC, FC, and STA samples

		End point temperature (°C)		
Oven temperature (°C)	*Oven type*	*65*	*72*	*80*
	NC	3.4 (±0.6)^{a,d}	3.6 (±0.1)^{a,f}	2.5 (±0.3)^{a,d}
180	FC	2.6 (±0.1)^{a,e}	2.6 (±0.1)^{a,g}	2.9 (±0.4)^{a,e}
	STA	2.3 (±0.3)^{a,f}	2.5 (±0.3)^{a,i}	2.6 (±0.4)^{a,f}
	NC	2.1 (±0.1)^{b,d}	2.9 (±0.1)^{bc,f}	3.0 (±0.5)^{b,d}
210	FC	3.7 (±0.7)^{b,e}	4.7 (±0.7)^{b,h}	3.3 (±0.0)^{b,e}
	STA	2.3 (±0.3)^{b,f}	2.5 (±0.2)^{c,i}	3.9 (±0.1)^{b,g}
	NC	2.3 (±0.3)^{c,d}	2.8 (±0.5)^{d,f}	2.3 (±0.0)^{c,d}
240	FC	2.3 (±0.3)^{c,e}	4.8 (±0.2)^{e,h}	3.5 (±0.5)^{c,e}
	STA	2.4 (±0.6)^{c,f}	2.2 (±0.2)^{d,i}	2.5 (±0.2)^{c,f}

NC: natural convection; FC: forced convection; STA: steam-assisted hybrid oven;
All data are reported as means (±standard deviations) of two parallel evaluations;
The different letters after the values in the same column indicate that the means is different significantly ($p < 0.05$);
First letters indicate difference between oven types in the same cooking temperature, second letters indicate difference between cooking temperatures in the same oven. None of the letters indicate comparison between the rows.

layer on the surface of samples caused the dripping of fat from the meat easily, decreasing of the fat retention value. On the contrary, the fat retention values in the FC samples were higher than other samples because of the early formation of a crust layer. The fat retention (%) values of samples cooked in saturated SO were determined as 34.66 (±4.44)%, 25.79 (±5.89)%, and 22.89 (±2.16)% for the end-point temperatures of 65, 72, and 80°C, respectively.

The CIE color values of raw meat were 45.98 ± 1.02 (L^*), 19.83 ± 1.56 (a^*), and 12.03 ± 0.70 (b^*). Meat cooking in the STA caused significant changes in CIE color values (L^*, a^*, b^*; $p < 0.05$). Increasing of oven temperature and end-point temperatures of samples caused a decrease in L^* values as stated by Deniz and Serdaroglu.[36] Meat cooked in the STA oven was characterized by higher values of L^* and lower values of a^* (Table 4). The lower a^* values of STA samples may be explained by the short cooking time and also the effect of steam that might reduce redness probably linked to a different protein denaturation pattern. The highest a^* values were observed at samples cooked in a FC oven and a significant decrease in a^*value was determined with increasing cooking time due to burning and darkening of surface of these samples. Color change and ΔE values of all samples were observed with increasing end-point temperatures. Color change in STA samples was limited as compared with other samples. The SO samples had the highest L^* and the lowest a^* values among all cooked samples and comparatively high ΔE values (Table 4).

A sensory evaluation was carried out to assess the overall acceptance of NC, FC, STA, and SO samples. The panel generally preferred FC samples that had a well-roasted appearance on the surface and also medium of doneness, whereas the results indicated no significant difference ($p > 0.05$) between samples (Table 5). The STA samples had nearly same degree of likeness as compared with other convectional oven samples; moreover at some conditions, these samples were more preferred than NC and FC samples. The overall acceptance values of samples cooked in saturated SO were determined as 1.7(±0.7), 1.7(±0.0), and 2.1(±0.1) for the end-point temperatures of 65, 72, and 80°C, respectively. The acceptance of SO samples was considerably low as it is expected because of pale surface color.

CONCLUSIONS

The different oven types (NC, FC, steam-assisted hybrid, and saturated steam) at different temperatures led to different physical, chemical, and sensory properties of cooked meat. Forced convective cooking had the highest cooking time compared to the other treatments and the samples looked parched with a uniform crust formation and some non-enzymatic browning (Maillard reactions). Soluble protein degradation was fitted by the first order reaction kinetics and in STA had higher reaction rate constants compared to that of convection ovens. The steam assisted hybrid cooked samples had shorter cooking time and lower cook values, besides they had considerably low HCAs content, low fat values, and had almost same degree of likeness. Steam-assisted hybrid cooking could be considered as an alternative cooking method to obtain a healthier product without compromising the eating habits of conventional methods and a product retaining the most of the nutritional values.

FUNDING

This research was supported by the Scientific and Technical Research Council of Turkey (Project No. TUBITAK-TOVAG 109 O 087). Also, the equipment and material support of the companies of Arcelik A.S. and Pinar Et A.S. is acknowledged.

REFERENCES

1. Özcan, A.U.; Bozkurt, H. Physical and Chemical Attributes of a Ready-to-Eat Meat Product During the Processing: Effects of Different Cooking Methods. International Journal of Food Properties **2015**, DOI:10.1080/10942912.2014.982256
2. Barbanti, D.,; Pasquini, M. Influence of Cooking Conditions on Cooking Loss and Tenderness of Raw and Marinated Chicken Breast Meat. Food Science and Technology **2005**, *38*, 895–901.
3. Kahlon, T.S.; Chiu, M.M.,; Chapman, M.H. Steam Cooking Significantly Improves in Vitro Bile Acid Binding of Beets, Eggplant, Asparagus, Carrots, Green Beans, and Cauliflower. Nutrition Research **2007**, *27*, 750–755.
4. Kahlon, T.S.; Chiu, M.M.,; Chapman, M.H. Steam Cooking Significantly Improves in Vitro Bile Acid Binding of Collard Greens, Kale, Mustard Greens, Broccoli, Green Bell Pepper, and Cabbage. Nutrition Research **2008**, *28*, 351–357.
5. Murphy, R.Y.; Johnson, E.R.; Duncan, L.K.; Clausen, E.C.; Davis, M.D.; March, J.A. Heat Transfer Properties, Moisture Loss, Product Yield, and Soluble Proteins in Chicken Breast Patties During Air Convection Cooking. Poultry Science **2001**, *80*, 508–514.
6. Vittadini, E.; Rinaldi, M.; Chiavaro, E.; Barbanti, D.; Massini, R. The Effect of Different Convection Cooking Methods on the Instrumental Quality and Yield of Pork Longissimus Dorsi. Meat Science **2005**, *69*, 749–756.
7. Danowska-Oziewicz, M.; Karpinska-Tymoszczyk, M.; Borowski, J. The Effect of Cooking in a Steam-Convection Oven on the Quality of Selected Dishes. Journal of Foodservice **2007**, *18*, 187–197.
8. Isleroglu, H.; Kemerli, T.; Kaymak-Ertekin, F. Effect of Steam Assisted Hybrid Cooking on Textural Quality Characteristics, Cooking Loss, and Free Moisture Content of Beef. International Journal of Food Properties **2015**, *18*, 403–414.
9. Mora, B.; Curti, E.; Vittadini, E.; Barbanti, D. Effect of Different Air/Steam Convection Cooking Methods on Turkey Breast Meat: Physical Characterization, Water Status, and Sensory Properties. Meat Science **2011**, *88*, 489–497.
10. Sugimura, T.; Nagao, M.; Kawachi, T.; Honda, M.; Yahagi, T.; Seino, Y.; Sato, S. Mutagens-Carcinogens in Foods, with Special Reference to Highly Mutagenic Pyrolytic Products in Broiled Foods. In *Origins of Human Cancer*; Hiatt, H.H.; Watson, J.D.; Winsten, J.A.; Eds.; Cold Spring Harbor Laboratory Press: Cold Spring Harbor, NY, **1977**; 1561–1577 pp.
11. Felton, J.S.; Healy, S.K.; Stuermer, C.; Berry, H.; Timourian, H.; Hatch, F.T.; Morris, M.; Bjeldanes, L.F. Mutagens from the Cooking of Food (1) Improved Isolation and Characterization of Mutagenic Fractions from Cooked Ground Beef. Mutation Research **1981**, *88*, 33–44.

12. Ohgaki, H.; Hasegawa, H.; Suenaga, M.; Sato, S.; Takayama, S.; Sugimura, T. Carcinogenicity in Mice of a Mutagenic Compound, 2-Amino-3,8-Dimethylimidazo(4,5-F) Quinoxaline (Meiqx), from Cooked Foods. Carcinogenesis **1987**, *8*, 665–668.
13. Adamson, R.H.; Thorgeirsson, U.P.; Snyderwine, E.G.; Thorgeirsson, S.S.; Reeves, J.; Dalgard, D.W.; Takayama, S.; Sugimura, T. Carcinogenicity of 2-Amino-3-Methylimidazo[4,5-F]Quinoline in Nonhuman Primates: Induction of Tumors in Three Macaques. Japanese Journal of Cancer Research **1990**, *81*, 10–14.
14. Ito, S.; Provini, L.; Cherubini, E. L-Homocysteic Acid Mediates Synaptic Excitation at NMDA Receptors in the Hippocampus. Neuroscience Letters **1991**, *124*, 157–161.
15. Klassen, R.D.; Lewis, D.; Lau, B.P.-Y.; Sen, N.P. Heterocyclic Aromatic Amines in Cooked Hamburgers and Chicken Obtained from Local Fast Food Outlets in the Ottawa Region. Food Research International **2002**, *35*, 837–847.
16. Sugimura, T. Nutrition and Dietary Carcinogens. Carcinogenesis **2000**, *21*, 387–395.
17. Kobayashia, M.; Hanaokaa, T.; Nishiokab, S.; Kataokab, H.; Tsuganea, S. Estimation of Dietary HCA Intakes in a Large-Scale Population-Based Prospective Study. Japanese Mutation Research **2002**, *506–507*, 233–241.
18. Murkovic, M.; Friedrich, M.; Pfannhauser, W. Heterocyclic Aromatic Amines in Fried Poultry Meat. Zeitschrift Für Lebensmittel-Untersuchung Und-Forschung A **1997**, *205*, 347–350.
19. Skog, K.; Johansson, M.A.; Jagerstadt, M.I. Carcinogenic Heterocyclic Amines in Model Systems and Cooked Food: A Review on Formation, Occurrence, and Intake. Food and Chemical Toxicology **1998**, *36*, 879–896.
20. AOAC. *Official Methods for Analysis*, 15th Ed; Association of Official Analytical Chemists: Arlington, VA, **1990**.
21. Folch, J.; Lees, M.; Stanley, G.H.S. A Simple Method for the Isolation and Purification of Total Lipids from Animal Tissues. Journal of Biological Chemistry **1957**, *226*, 497–509.
22. Holdsworth, S.D. Optimization of Thermal Processing—A Review. Journal of Food Engineering **1985**, *4*, 89–116.
23. Poon, P.W.B.; Durance, T.; Kitts, D.D. Composition and Retention of Lipid Nutrients in Cooked Ground Beef Relative to Heat Transfer Rates. Food Chemistry **2001**, *74*, 485–491.
24. Bradford, M.M. A Rapid and Sensitive Method for the Quantitation of Microgram Quantities of Protein Utilizing the Principle of Protein-Dye Binding. Analytical Biochemistry **1976**, *72*, 248–254.
25. Özdestan, Ö.; Kaçar, E.; Keşkekoğlu, H.; Üren, A. Development of a New Extraction Method for Heterocyclic Aromatic Amines Determination in Cooked Meatballs. Food Analytical Methods **2014**, *7*, 116–126.
26. Serdaroglu, M. Improving Low Fat Meatball Characteristics by Adding Whey Powder. Meat Science **2006**, *72*, 155–163.
27. CIE. Commission Internationale de l_eclairage. *Recommendations on Uniform Colorspaces-Color Equations, Psychometric Color Terms*, Supplement No. 2 to CIE Publ. No. 15 (E-1.3.L) 1971/9TC- 1-3., CIE: Paris, France, **1978**.
28. Amerine, M.A.; Pangborne, R.M.; Roessler, E.B. *Principles of Sensory Evaluation of Food*; Academic Press: New York, NY, **1965**; 602 p.
29. Isleroglu, H.; Kemerli, T.; Sakin-Yilmazer, M.; Guven, G.; Ozdestan, O.; Uren, A.; Kaymak-Ertekin, F. Effect of Steam Baking on Acrylamide Formation And Browning Kinetics Of Cookies. Journal of Food Science **2012**, *77*, 257–263.
30. Skog, K.; Jägerstad, M. Effects of Monosaccharides and Disaccharides on the Formation of Food Mutagens in Model Systems. Mutation Research **1990**, *230*, 263–272.
31. Arvidsson, P.; Boekel, M.A.J.S.V.; Skog, K.; Jägerstad, M. Kinetics of Formation of Polar Heterocyclic Amines in a Meat Model System. Journal of Food Science **1997**, *62*, 911–916.
32. Sinha, R.; Rothman, N.; Brown, E.D.; Salmon, C.P.; Knize, M.G.; Swanson, C.A.; Rossi S.C.; Mark, S.D.; Levander, O.A.; Felton, J.S. High Concentrations of the Carcinogen 2-Amino-1-Methyl-6-Phenylimidazo[4,5-B]Pyridine [Phip) Occur in Chicken But Are Dependent on the Cooking Method. Cancer Research **1995**, *55*, 4516–4519.
33. Skog, K.; Steineck, G.; Augustsson, K.; Jagerstad, M. Effect of Cooking Temperature on the Formation of Heterocyclic Amines in Fried Meat Products and Pan Residue. Carcinogenesis **1995**, *16*, 861–867.
34. Skog, K.; Augustsson, K.; Steineck, G.; Stenberg, M.; Jägerstad, M. Polar and Non-Polar Heterocyclic Amines in Cooked Fish and Meat Products and Their Corresponding Pan Residues. Food and Chemical Toxicology **1997**, *35*, 555–565.
35. Sinha, R.; Rothman, N.; Salmon, C.P.; Knize, M.G.; Brown, E.D.; Swanson, C.A. Heterocyclic Amine Content in Beef Cooked by Different Methods to Varying Degrees of Doneness and Gravy Made from Meat Drippings. Food and Chemical Toxicology **1998**, *36*, 279–287.
36. Deniz, E.E.; Serdaroglu, M. Effects of Nitrite Levels, Endpoint Temperature, and Storage on Pink Color Development in Turkey Rolls. European Food Research and Technology **2003**, *217*, 471–474.