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Research Paper / Araştırma Makalesi

Effect of Vacuum Cooking Process Conditions on Color, Textural, Microstructural and Sensory Properties of Beef

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ABSTRACT

In this study, the effect of vacuum cooking conditions (temperature and time) on the color, textural, microstructural and sensory quality of beef samples was investigated. In order to determine the optimum cooking temperature (60-90ºC) and time (80-120 min) for beef, an optimization study was carried out following Central Composite Rotatable Design (CCRD). The optimum vacuum cooking condition was selected as 85.6°C of cooking temperature and 106.6 min of cooking time targeting maximum chewiness (textural quality), minimum shear force (textural quality) and maximum sensory overall acceptance attributes. Considering the color values of crust and inner parts of beef samples, an insignificant difference was observed among cooking temperatures and times. However, Warner Bratzler shear force values decreased with an increase in cooking temperature. Moreover, higher cooking temperature and longer cooking time resulted in superior sensorial properties in terms of overall acceptance scores.

Keywords: Vacuum cooking, Beef, Optimization, Texture, Color

Vakum Pişirmede İşlem Koşullarının Kırmızı Etin Renk, Tekstür, Mikroyapı ve Duyusal Özellikleri Üzerine Etkisi

ÖZ

Bu çalışmada vakumlu pişirme işlem koşullarının (sıcaklık ve süre) kırmızı etin renk, dokusal, mikroyapısal ve duyusal kalite üzerine etkisi araştırılmıştır. Kırmızı etin optimum pişirme sıcaklığını (60-90ºC) ve süreyi (80-120 min) belirlemek için Merkezi Tümleşik Tasarım (CCRD) ile optimizasyon çalışması yapılmıştır. Optimum vakum pişirme koşulu, maksimum çiğneme (dokusal kalite), minimum kesme kuvveti (dokusal kalite) ve maksimum duyusal genel kabul özelliklerini hedef alarak 85.6°C pişirme sıcaklığı ve 106.6 dakika pişirme süresi olarak belirlenmiştir. Kırmızı et numunelerinin kabuk ve iç kısımlarının renk değerleri göz önüne alındığında, farklı pişirme sıcaklığı ve süre arasında önemli bir fark gözlenmemiştir. Warner Bratzler kesme kuvveti değerleri, pişirme sıcaklığı arttıkça azalmıştır. Ayrıca, daha yüksek pişirme sıcaklığı ve daha uzun pişirme süresi, genel kabul puanları açısından daha iyi duyusal özellikler ortaya çıkmıştır.

Anahtar Kelimeler: Vakum pişirme, Kırmızı et, Optimizasyon, Tekstür, Renk

INTRODUCTION

Cooking process provides many positive effects on meat quality such as enhancing taste and flavor, improving digestibility, ensuring microbiological safety and increasing shelf life. During the cooking process, the meat undergoes some changes in its physical properties (i.e. color, texture) and it is subjected to chemical reactions (i.e. protein denaturation, Maillard reactions) that influence its final quality and acceptability such as aroma formation, shrinkage, firmness, changing in the amount of fat and protein fractions, increasing in pH, losses of minerals and changing of microbiological load [1]. It is well known that cooking conditions (time and temperature) and cooking methods are among the factors that mostly affect the final quality of meat products [2].

Cooking method of meat is generally determined according to the basic traits related to consumer preferences as flavour, tenderness, colour and appearance [3, 4]. The most preferred cooking methods are grilling, sauteing, and deep fat frying and boiling. In the grill type cooking method using a high heat source, the formation of dangerous carcinogenic mutagenic agents (PAH, HCA) is accelerated [5].

An alternative cooking method, called vacuum boiling or cooking, has been applied in haute cuisine restaurants from the beginning of its development to prevent the formation of unhealthy substances caused by high temperatures. Vacuum boiling consists of cooking in boiling water at below 100°C by lowering the pressure to reach the vapour pressure of water. The low pressure is maintained during cooking by the continuous function of the pump. Few scientific studies have been found in the literature about the application of this technique to cook vegetables and fruits in water [3, 6, 7]. Vacuum cooking of meat has not been commonly used in the food processing industry. The purpose of vacuum cooking of meat is to decrease the temperature to be applied to a level at which the quality deteriorations are minimized. However, a study about vacuum cooking of meat is not available in the literature.

Low-temperature heating methods provide juicy meat by improving the water holding capacity of the muscle tissue during cooking. Below 60°C, mainly transverse muscle fiber shrinkage occurs while at higher temperatures a severe longitudinal shrinkage takes place, which significantly reduces cooking yield [8, 9]. Furthermore, higher cooking temperatures lead to myofibrillar protein alterations with a toughening effect [10], which can be avoided under low temperature conditions. Maintaining these low core temperatures for a prolonged time has a tenderizing effect, which is mainly caused by a weakening in connective tissue strength [11-13].

The primary aim of the present study was to investigate the effects of vacuum cooking conditions on color, textural, microstructural and sensory quality of beef. Secondly, the optimum vacuum cooking condition (time and temperature) was determined, following Central Composite Rotatable Design (CCRD), targeting maximum chewiness (textural quality), minimum shear force (textural quality) and maximum sensory overall acceptance attributes. The determination of optimum process conditions with regards to energy efficiency and food quality will provide the available data for the food industry in future studies.

MATERIALS and METHODS

Materials

Beef eye of round (semitendinosus muscle) was purchased from a local butcher, in Izmir, Turkey shortly after slaughter. Samples were obtained daily and stored at 4°C before the cooking process.

Design of the Vacuum Cooking Equipment Prototype

A vacuum cooking equipment prototype was designed and developed for cooking, frying and evaporation purposes, which can operate in a wide range of vacuum pressure and atmospheric pressure as well. The schematic diagram of this equipment was given in Figure 1. The same equipment was used to produce strawberry jam as discussed by Okut et al. [14] and to cook peas and carrots as given by Koç et al. [15]. The developed equipment made up a 6 L vessel equipped with a reductor mixer that worked in the 0–50 Hz range continuously or batch, an electrical heater with 1.5 kW power, an oily type vacuum pump of 0.41 kW power and a condenser of 1 kW power. PLC system was used to control mixer rate, vacuum level and cooking time, while PID system was used to control the electrical heater. The internal temperature of the cooker, vapor temperature at the condenser's exit and the internal pressure of the cooker were recorded per each 3 s.

Cooking Methods

Raw beef was cut into 2x2x1 cm quadratic slices to obtain homogeneously cooked beef pieces. The beef pieces were weighed as 200 g and put into a cooking basket. The cooking basket was stand up until the cooking water reached the desired temperature and then the basket was pulled down into the cooking water without allowing the vacuum to be broken.

Beef samples were cooked at different temperatures and times under vacuum to understand the effect of the process conditions on cooking quality. The vacuum pressure inside the cooker was applied according to the vapor pressure of water for each cooking temperature, therefore absolute pressure was varied in the range of 20 to 70 kPa (for vacuum method, absolute pressure was 20, 25, 40, 60, 70 kPa at 60, 64.4, 75, 85.6 and 90°C, respectively). The process conditions of vacuum cooking method were arranged according to CCRD experimental design as shown in Tables 1, 3 and 5

All cooking experiments were performed in replicate for each operating condition, besides each analysis in thrice.

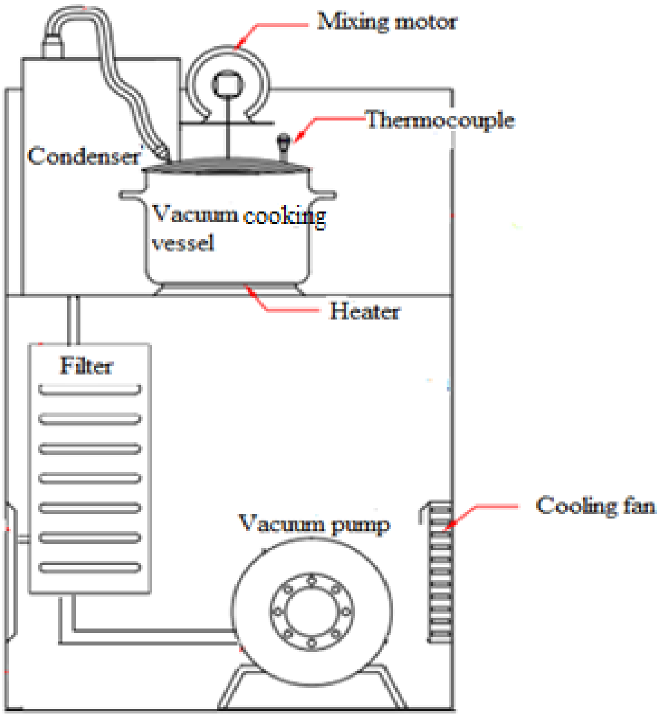

Figure 1. Vacuum cooking equipment prototype

Analyses

Color Analysis

The color was measured on the surface of the cooked samples using a colorimeter (Minolta, DP-40 Konica Minolta, Osaka, Japan) as Commission Internationale de l'eclairage (CIE) Lab color parameters, L* (lightness), a* (redness), b* (yellowness). The measurements of the outer and the inner part of the cooked beef pieces were repeated at four randomly selected locations on each sample. The color intensity (Chroma, C*) values were calculated with Eq. 1 [16-17].

$$C^* = (a^{*2} + b^{*2})^{1/2} \quad (1)$$

Texture Analysis

Texture analysis was performed by means of both Warner Bratzler shear test (WB) and Texture Profile Analysis (TPA), using TA.XT2 Texture Analyzer (Texture Analyzer TA-XT2, Stable Micro Systems, Haslemere, UK) with a 30 kg load cell for each cooked sample and raw beef sample before the cooking process. Samples were kept 2 h at room temperature after cooking and then cut into pieces of 1x1x2 cm for the WB shear test and 1x1x1cm for TPA. WB shear test was achieved using Warner-Bratzler knife with triangular cut-out, perpendicularly to the direction of the muscle-fiber arrangement with the following testing procedure: pre-test speed 2 mm/s, test speed 1.5 mm/s and trigger force 20 g. The maximum shear force (WBSF) required to shear the sample and the work after the maximum force were measured and that work was taken as a measure of toughness.

TPA was performed using a 36 mm diameter of cylindrical probe with the following settings: pre-test speed 1 mm/s, test speed 1 mm/s, time interval between first and second stroke 3 s, trigger force 5 g and final strain 80%. TPA parameters of hardness, adhesiveness, chewiness, springiness and cohesiveness were determined from the force-time plot of TPA curves. Hardness (N) was defined as the force required during the first compression. Adhesiveness (g.s) was the negative force area under the baseline between the compression cycles representing the work necessary to pull the compressing plunger away from the sample if the material exhibits stickiness during decompression. Springiness, the rate at which sample returns to original shape after compressions, was calculated from the ratio of time difference of the second cycle to the first cycle. Cohesiveness, a measure of the internal strength of the bonds that make up the product, was the ratio of the positive area of the second cycle to the positive area of the first cycle. There are no units for springiness and cohesiveness. Chewiness (N) was the product of hardness (N), springiness and cohesiveness. 10 sample cuts were analyzed for each cooking test [18].

Microstructure

Microstructure measurements of the raw and cooked meat samples were carried out by using Micro Computer Tomography (Micro-CT) equipment (Scanco Medical µCT 50, Switzerland). 3D models were created with the images received cross-section of the sample by using X-rays [19].

Sensory analysis

Sensory analysis was carried out for appearance, color, hardness (texture), smell, taste and overall acceptance by 10 semi-trained panelists [20]. The intensity of the properties was determined using a 5-point hedonic scale (1 being the lowest and 5 the highest). 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 sessions were evaluated in random order with 2 h break between sessions. Sensory analyses were carried out at daylight and room temperature [21].

Experimental Design and Statistical Analysis

Response surface methodology (RSM) was used to investigate the main effects of the independent variables (cooking temperature and time) on the shear force, chewiness and the sensory quality of the meat during cooking of beef samples. Cooking temperature (60-90°C) and cooking time (80-120 min) were chosen as independent variables with respect to literature research and pre-elementary tests. A Central Composite Rotatable Design (CCRD) was performed that includes 13 experiments formed by 5 central points (Table 1).

For vacuum cooking, all experimental data were fitted to a second-order polynomial model. Regression coefficients were obtained for each response. Significant terms in the models were found through analysis of variance (ANOVA) by using Design Expert Ver. 7.0.0 software.

For each result ANOVA at a confidence level of 95% was carried out. Also, one sample t-test was evaluated using SPSS version 13.0 Windows program (SPSS Inc., Chicago, IL) to test the significant differences between the results estimated by model and obtained by optimum point experiments.

Optimization

Numerical methods were used for optimization (desirability function) [22]. At least five experiments were followed out at the optimum point as determined by the model (the optimum process conditions) and the optimum point was confirmed experimentally. In this study, desirability functions were evaluated for the criteria of maximum chewiness, minimum shear force and maximum sensory attributes. Response surface graphs and contour lines that helps to determine the optimum point is plotted using models obtained by regression analysis.

RESULTS and DISCUSSION

The color, textural and sensorial properties of the beef samples cooked under vacuum at different experimental conditions are given in Tables 1, 3 and 5. For the determination of the statistical significance of the model terms and to fit the model, ANOVA and regression analysis were carried out, as given in Tables 2, 4 and 6. The quadratic polynomial model represented significantly the experimental values of responses at $p<0.05$ levels, besides the lack of fit of models were not significant.

Table 1. Crust and inner part color (CIE L*, a*, b*) and color intensity (C*) values of the beef samples cooked under vacuum at different conditions

Temperature	Time	Crust				Inner part			
(°C)	(min)	L*	a*	b*	C*	L*	a*	b*	C*
64.4	85.9	58.93	8.56	13.45	15.85	62.54	10.41	11.53	15.62
85.6	85.9	48.92	11.49	10.80	15.86	52.21	9.64	12.08	15.49
64.4	114.1	56.69	9.41	12.19	15.48	61.09	7.70	11.16	13.67
85.6	114.1	49.96	7.08	12.87	14.84	58.06	8.67	12.14	14.98
60.0	100.0	61.45	6.92	11.84	13.75	62.36	10.03	11.45	15.37
90.0	100.0	51.57	12.32	12.33	17.70	55.74	9.40	11.38	14.88
75.0	80.0	35.82	4.86	9.50	10.67	38.82	5.20	7.91	9.54
75.0	120.0	52.58	10.78	13.65	17.54	58.07	8.11	11.24	13.85
75.0	100.0	49.88	11.79	12.39	17.40	57.93	9.11	12.09	15.16
75.0	100.0	53.97	8.55	13.52	16.14	60.67	8.61	11.85	14.71
75.0	100.0	53.59	7.97	13.46	15.78	61.04	7.68	11.49	13.87
75.0	100.0	51.18	8.93	13.86	16.61	58.27	8.24	12.29	14.85
75.0	100.0	55.92	7.26	13.42	15.28	58.14	8.98	11.38	14.54

Consumers have been advised that the absence of pink color can be an indicator of thorough cooking (internal temperature of 717C, USDA, 1994). However, we have observed a red internal color in patties cooked to 717C. This phenomenon seemed to be more frequent in products containing 20% fat (Berry, 1992, 1994; Berry and Stanfield, 1993). Consumers have been advised that the absence of pink color can be an indicator of thorough cooking (internal temperature of 717C, USDA, 1994). However, we have observed a red internal color in patties cooked to 717C. This phenomenon seemed to be more frequent in products containing 20% fat (Berry, 1992, 1994; Berry and Stanfield, 1993).

Color measurement in cooked meat products can provide reliable information about eating quality attributes and consumer acceptance. Because of the absence of pink color seems an indicator of appropriate cooking of the meat product by consumers. The results of color evaluation on cooked beef samples under vacuum are given in Table 1 for all vacuum cooking conditions. The CIE color values of raw beef were 45.98±1.02 (L*), 19.83±1.56 (a*), and 12.03±0.70 (b*). Prior to the vacuum cooking process, all samples were stored and prepared at the same conditions, so the initial myoglobin's redox state for all samples could be accepted as same. The redox state of beef muscle myoglobin affects cooked color because each derivative differs in its thermal stability [23].

When the results of ANOVA were evaluated, it was determined that the crust color values of beef samples (L*, a*, b* and C*) could not be explained with quadratic model (p> 0.05). For the inner part, only L* values of beef pieces were found to be in agreement with the quadratic model (p<0.05) and these values were affected by cooking temperature and time at significant level (p<0.05) (Table 2).

No significant difference was generally observed among cooking temperatures and times (p>0.05) with respect to the color values of crust of beef samples. Similarly, Becker et al. [24] found that there were insignificant differences in a* and b* values of pork meat between heated for 20 h at 53°C and low temperature heated to 60°C core temperature.

Table 2. ANOVA results for color analysis of vacuum cooked beef

Variation source	*p*- values							
	Crust				İnner part			
	L*	a*	b*	C*	L*	a*	b*	C*
Model	0.053	0.567	0.077	0.458	0.010*	0.352	0.301	0.347
X_1	0.036*	0.242	0.636	0.372	0.015*	0.849	0.633	0.91
X_2	0.099	0.480	0.036*	0.153	0.008*	0.903	0.167	0.412
X_1 X_2	0.707	0.287	0.111	0.863	0.285	0.506	0.838	0.642
X_1^2	0.143	0.607	0.193	0.878	0.555	0.123	0.789	0.296
X_2^2	0.061	0.630	0.066	0.228	0.011	0.178	0.071	0.093
Lack of fit	0.061	0.181	0.077	0.022*	0.106	0.028*	0.013*	0.007*

* Significant differences at 0.05 levels X_1: Temperature (ºC), X_2: Time (min)

The lowest a* value (redness) of the inner part and the crust of beef were found at 70°C for 80 min cooking. The amount of myoglobin, its redox status and the heat-dependent denaturation have determined the red color of cooked meat [25]. The redness is influenced by the heat treatment, the cooking method, the cooking time and temperature. An increase in cooking temperature increases the brown color and decreases the pink color [10]. According to Hunt et al. [23], deoxymoglobin, which is predominant redox state of myoglobin immediately after cutting, denatures at temperatures of 65 to 75°C. In this study, a* value of raw beef was 19.83±1.56 and all the vacuum cooked beef had lower a* value than the raw beef. It can be explained that the vacuum cooking above 60°C might denature major amounts of myoglobin. However, no significant changes were observed in the a* values of beef samples with the cooking temperature and time (Tables 1 and 2). The shorter cooking time might play a role in the reduced a* values. The lower a* values of the samples may be explained by the short cooking time and also the effect of vacuum that might reduce the redness probably linked to a different protein denaturation pattern. Increasing of cooking temperature of samples caused a decrease in L* values. Also, L* values of inner part of beef samples were found to be higher than the crust of the samples. Moreover, the beef pieces cooked at 75°C and 80 minutes had lower b* and C* values. This could be explained with the myoglobin denaturation of meat during cooking, which changes from bright red or pink colors to more opaque brown colors or paler shades when meat is cooked.

However, as Van Laak et al. [26] investigated a red internal color in patties cooked to 71°C, we also determined the same phenomenon for the beef pieces cooked at 75°C as well. This phenomenon has been related with the products containing 20% fat [27].

Table 3. WBSF (N) and TPA results of beef cooked under vacuum at different conditions

Temperature (°C)	Time (min)	Shear Force (N)	Hardness (N)	Adhesiveness (dimensionless)	Chewiness (N)	Springiness (dimensionless)	Cohesiveness (dimensionless)	Gumminess (N)
64.4	85.9	71.59	258.4	-2.41	72.23	0.51	0.60	144.9
85.6	85.9	50.37	156.03	-0.74	38.39	0.45	0.55	85.56
64.4	114.1	59.43	193.47	-1.95	57.78	0.49	0.56	107.15
85.6	114.1	33.03	199.6	-1.23	55.14	0.51	0.54	108.10
60.0	100.0	63.26	190.98	-2.41	52.46	0.46	0.57	103.54
90.0	100.0	31.51	154.8	-1.04	37.92	0.52	0.53	82.14
75.0	80.0	60.18	226.44	-2.06	64.45	0.49	0.58	131.64
75.0	120.0	46.35	213.95	-0.24	65.92	0.56	0.55	118.40
75.0	100.0	50.6	252.32	-2.04	67.19	0.46	0.58	145.33
75.0	100.0	45.6	230.20	-2.27	65.24	0.50	0.57	131.28
75.0	100.0	49.02	252.72	-2.49	71.17	0.49	0.56	142.78
75.0	100.0	56.18	254.96	-2.91	71.89	0.50	0.57	145.12
75.0	100.0	49.08	247.91	-3.48	73.59	0.50	0.59	146.89

In literature, textural properties of cooked meat are generally related with zoo technical characteristics of the animal [28], anatomical characteristics such as type of muscle, factors external to the animal, as handling and feeding characteristics, or technological characteristics like electrical stimulation [29] or cooking method [30, 31]. The hardness (N) and WBSF (N) values of vacuum cooked beef determined by TPA and WB shear tests are given in Table 3, respectively.

Table 4. ANOVA results for texture analysis of vacuum cooked beef

Variation source	*p*- values						
	Shear force	Hardness	Adhesiveness	Chewiness	Springiness	Cohesiveness	Gumminess
Model	0.000*	0.000*	0.032*	0.000*	0.247	0.003*	0.000*
X_1	<0.000*	0.001*	0.030*	0.001*	0.553	0.001*	0.002*
X_2	0.001*	0.215	0.156	0.663	0.093	0.009*	0.096
$X_1 X_2$	0.462	0.001*	0.425	0.003*	0.172	0.161	0.002*
X_1^2	0.583	<0.000*	0.091	<0.000*	0.589	0.010*	<0.000*
X_2^2	0.051	0.015*	0.013*	0.141	0.246	0.456	0.012*
Lack of fit	0.763	0.47	0.497	0.515	0.106	0.966	0.497

* Significant differences at 0.05 levels; X_1: Temperature (ºC), X_2: Time (min)

During cooking, hardening of myofibrillar proteins due to increasing of internal temperature has a toughening effect on meat muscle. WBSF (N) is especially taken as an indicator of hardness and gives more information on the extent of denaturation of the myofibrillar proteins that resulted in shrinkage of the muscle fibers, in comparison with alterations of connective tissue component (i.e. collagen shrinkage and gelatinization) after cooking of meat. It was determined that WBSF (N) decreased with increase in cooking temperature (Table 3). On the other hand, both cooking temperature and time were found to have a significant effect on the WBSF of the cooked beef samples ($p<0.05$) (Table 4). Belew et al. [32] have categorized the WBSF results of 40 bovine muscles based on confidence intervals reported earlier by Shackelford et al. [33]. According to the categorization, shear force lower than 31.38 N determined as “very tender”, 31.38<shear force<38.25 N as “tender”, 38.25<shear force<45.11 N as “intermediate” and higher than 45.11 N as “tough”. In this study, only the beef samples vacuum cooked at 85.6°C for 114.1 min and 90°C for 100 min meet the criteria for “tender” category. WBSF results showed that vacuum cooked beef samples except above conditions were determined as “tough”. This could be attributed to the low fat content of the beef pieces used in this study. It has been agreed that low fat beef was not appropriate for vacuum cooking method. Since *Semitendinosus muscle* is mainly composed of myofibrillar proteins, WBSF values might be more determinant parameters than hardness values obtained from TPA for the correct evaluation of the hardness of meat. Similarly, Fabre et al. [34] found that the WBSF value of *Semitendinosus muscle* was determined 46,1 N for water bath method. In addition, they indicated that different cooking methods and muscle types had a significant effect on WBSF values.

According to ANOVA results, cooking temperature had a significant ($p<0.05$) effect on the hardness, adhesiveness, cohesiveness, gumminess and chewiness values of the vacuum cooked beef samples (Table 4). However, only the springiness values did not vary with the cooking temperature and time ($p>0.05$). The reason of statistically undifferentiated springiness values might be explained by the high core temperatures of samples that were already exceeded myosin and α-actinin denaturation temperature in all cooking temperatures [35] because the minimum core temperature was chosen 65°C for all cooking experiments except sample 90°C/100 min. Chewiness (N), calculated using hardness as a factor, which suggests resistance to compression force was probably the main textural property determining tenderness characteristics of beef. As seen in Table 3, chewiness and gumminess (N) values showed a significant decrease with the cooking temperature increased ($p<0.05$). The lowest chewiness and gumminess values were obtained at 90°C/100 min. It could be explained that cooking temperature effect on fiber shrinkage.

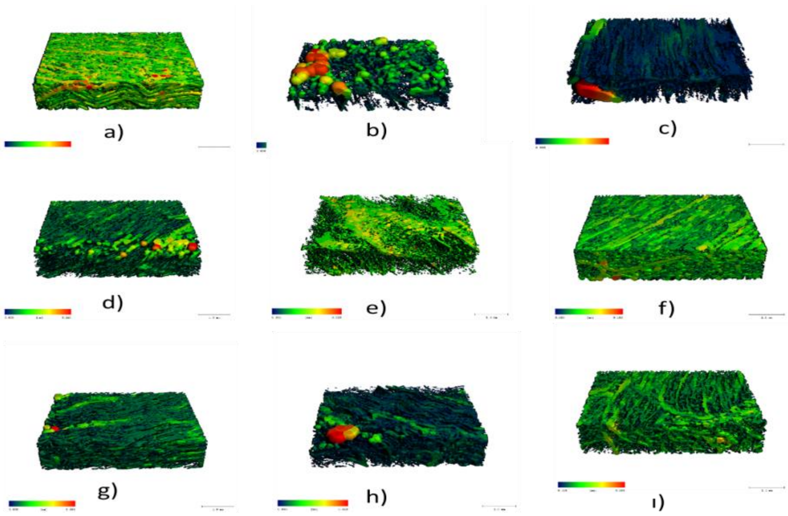

Figure 2. Micro-CT images of vacuum cooked beef a) 64.4°C-85.9 min; b) 85.6°C-85.6 min; c) 64.4°C -114.1 min; d) 85.6°C-114.1 min; e) 60°C-100 min; f) 90°C-100 min; g) 75°C-80 min; h) 75°C-120 min; i) 75°C-100 min

Microstructure of foods is considered as two-phase random media composed of a void phase (i.e., the pores) and a solid and/or liquid matrix phase (i.e., cells, cell walls, crystals, globules, oil droplets, etc.). The complex three-dimensional (3D) architecture of pores and matrix elements greatly affects the physical, sensorial and chemical properties of the food [36]. The microstructure of food changes because of simultaneous heat and mass transfer during cooking process. These changes play a key role in the formation of textural structure [37]. That's why, the structural changes in beef during cooking was analyzed with Micro Computer Tomography (Micro-CT) in this study. Micro-CT images of vacuum cooked beef are shown in Figure 2. In these images, the change of colors from blue to red indicated to enlarge the pore diameter of beef. The pore diameters increased with an increase in vacuum cooking temperature, but it was not exactly affected by cooking time. It could occur because both the loss of connection and breakage between the myofibrils and cooking loss can be observed in some areas, in addition to the appearance of some empty intercellular spaces.

Similarly, Christensen et al. [38] have observed that increasing cooking time has a smaller effect on diameter changes than the increased temperature and, thus in the pork longissimus heated at 53-59°C there were no clear differences in fiber diameter as cooking time was increased from 3 to 20 h. In the lamb longissimus cooked at 60, 70 or 80°C (6, 12 or 24 h of cooking), the fibers in micrographs were found to be smaller at 60°C, and no significant effect of time of cooking was determined [39].

Table 5. Sensory analysis results of vacuum cooked beef at different conditions

Temperature (°C)	Time (min)	Appearance	Color	Smell	Texture	Taste	Overall acceptance
64.4	85.9	2.17	2.33	2.33	2.3	2.17	2.33
85.6	85.9	3.10	3.00	3.30	3.50	2.90	3.63
64.4	114.1	2.63	2.63	3.13	2.13	2.13	3.00
85.6	114.1	4.17	4.17	4.00	4.39	4.00	4.38
60.0	100.0	2.40	2.30	2.30	2.60	2.40	2.50
90.0	100.0	3.80	3.30	3.40	4.20	3.60	3.88
75.0	80.0	3.50	3.44	3.22	3.28	3.50	3.19
75.0	120.0	3.50	3.33	3.50	3.83	3.50	3.83
75.0	100.0	3.20	3.20	2.80	3.30	3.10	3.38
75.0	100.0	3.20	3.60	3.60	3.10	3.30	3.60
75.0	100.0	3.33	3.50	2.67	3.33	3.00	3.75
75.0	100.0	2.83	3.17	2.83	3.00	3.00	3.25
75.0	100.0	3.17	3.33	3.17	3.50	3.50	3.50

Table 6. ANOVA results for sensory analysis of vacuum cooked beef

Variation	*p*- value					
Source	Appearance	Color	Smell	Texture	Taste	Overall acceptance
Model	0.013*	0.013*	0.045*	0.004*	0.026*	0.001*
X_1	0.001*	0.003*	0.008*	0.000*	0.003*	<0.000*
X_2	0.113	0.143	0.079	0.128	0.314	0.003*
$X_1 X_2$	0.340	0.167	0.882	0.113	0.143	0.831
X_1^2	0.435	0.028*	0.638	0.862	0.166	0.063
X_2^2	0.378	0.982	0.160	0.632	0.728	0.959
Lack of fit	0.088	0.108	0.751	0.105	0.088	0.530

* Significant differences at 0.05 levels; X_1: Temperature (ºC), X_2: Time (min)

Sensory evaluation was conducted to test the consumer's acceptance on the sensory properties of vacuum cooking beef in terms of appearance, color, smell, texture, taste and overall acceptance. 5-point (1=dislike very much, 5=like very much) hedonic scale was used to assess the overall liking of vacuum cooked beef samples and results are given in Table 5. Texture of beef is one of the most important criteria for consumer acceptance. A beef with rough is not acceptable by consumers. As seen in Table 5, the vacuum cooked beef sample at 85.6°C for 114.1 min possessed the highest for all sensory quality parameters. This condition is the combination of the highest temperature and time under vacuum. Texture scores increased with increasing cooking time and temperature; however cooking temperature was the most effective parameter on the texture and it was found to be statistically significant ($p<0.05$) (Table 5-6). In addition, correlation coefficients determined between texture scores and WBSF values were -0.89. The negative correlation indicated that consumer acceptance decreased with increasing WBSF values. Similarly, overall acceptance scores increased with increasing cooking time and temperature and these two variables were found to be statistically significant ($p<0.05$) (Table 6). For appearance, color, smell, texture and taste scores, only cooking temperature was found to be statistically significant ($p<0.05$) and these scores increased with increasing cooking temperature (Tables 5-6).

Vacuum cooked beef at low cooking temperature caused hardening of the tissue, leading to undesirable color, texture and mouthfeel. These undesired properties affected the quality characteristics of the beef and caused low scores given by the panelists.

Optimization

The optimum vacuum cooking process conditions in terms of cooking temperature and time were determined with targeting minimum shear force, maximum chewiness and maximum sensorial overall acceptance. The optimization procedure was performed with Design Expert version 7.0 software (Stat-Ease Inc., MN, USA). Second-order polynomial model was used for each response for determining the optimum point. Response surface and counter plot of chewiness, sensory overall acceptance and WBSF of vacuum cooked beef are given in Figure 3. As seen in Figure 3, a decrease in cooking temperature and time resulted in higher chewiness. Besides, the cooking temperature was found to be the most effective parameter on chewiness. The sensory overall acceptance score of the cooked beef increased linearly with increasing cooking temperature and time. At the maximum point of cooking time and temperature, the overall acceptance value reached the highest level. Besides, increased cooking time and temperature caused to decrease in the WBSF values.

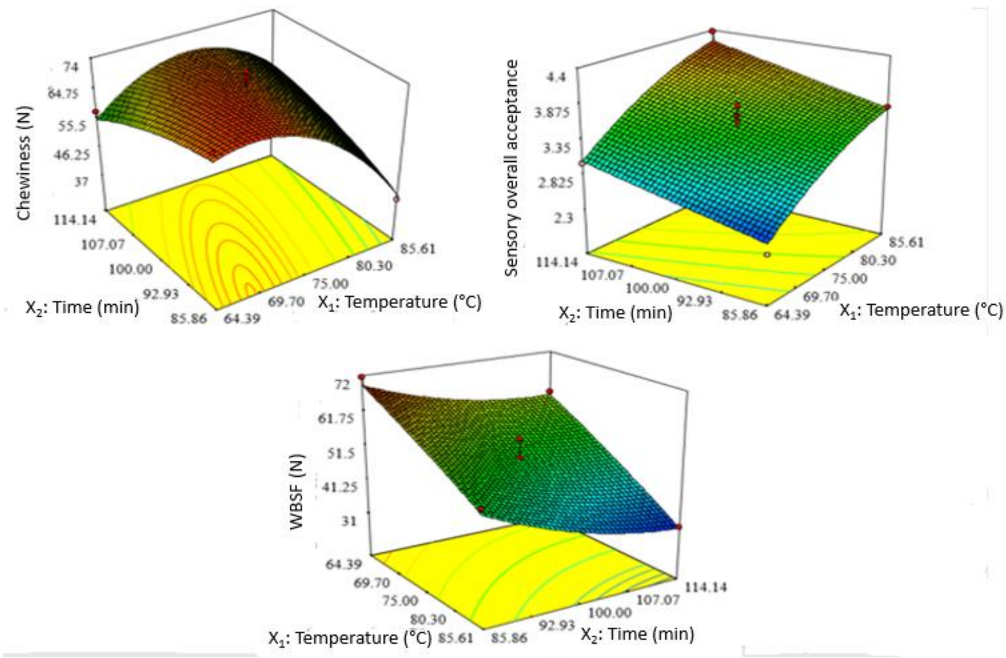

Figure 3. Response surface and contour plot of vacuum cooked beef

Table 7. Results of statistical analysis for verification of the optimization results

Responses	Predicted value	Experimental value[a]	SE[b]	Difference	% Error[c]	*p* value
WBSF	34.73	36.34	1.903	-1.61	0.044	0.446
Chewiness	53.98	52.95	0.043	0.07	0.018	0.179
Overall acceptance	4.06	3.99	1.390	1.03	0.020	0.499

[a] Experimental values were given as mean ± standard deviation; [b] Mean standard error; [c] %Error - $(|y_{exp}-y_{pre}|/y_{exp})*100$

The desirability function approach was applied to obtain the optimum point solution given in Table 7. The optimum point of cooking temperature and cooking time was found to be 85.6°C and 106.6 min. The WBSF value, the chewiness and the sensorial overall acceptance at the optimum point were determined as 34.73 N, 53.98 N and 4.06, respectively. The results of the five validation experiments at optimum vacuum cooking process conditions were also given in Table 7, comparatively as average results and the estimated values. The WBSF, the chewiness and the sensorial overall acceptance of the obtained samples were found to be not significantly (p>0.05) different from the predicted values determined by Design Expert.

According to the results of the validation test, it has been verified that the difference between all the responses and the estimated values from the model was not statistically significant (p>0.05). This result clearly showed that the optimization process was confirmed by verification trials.

CONCLUSION

In this study, the effects of vacuum cooking method on color, textural, microstructural and sensorial quality of beef were investigated. CCRD experimental design was used to determine the effects of vacuum cooking independent variables (temperature and time). Moreover, the optimum vacuum cooking process conditions were chosen with targeting maximum chewiness, minimum shear force and maximum sensory overall acceptance attributes. According to the results of the optimization study, cooking temperature of 85.6ºC and cooking time of 106.6 min. were found to be optimum point for vacuum cooking method of beef.

Vacuum cooked beef samples except the samples cooked at 85.6°C for 114.1 min and 90°C for 100 min were found to be tough according to Warner Bratzler Shear Force (WBSF) results. This has been related with the low fat content of the beef samples. In future studies, beef samples with higher fat content could be evaluated to determine the effect of vacuum cooking method on the textural quality of beef in a better way. Beef sample vacuum cooked at 85.6°C for 114.1 min has the highest overall sensory quality scores. This result is a clear understanding of higher cooking temperature and longer time leads to better textural quality and cooked color perception due to protein denaturation for vacuum cooking method. Even if the color properties and the Micro-CT results did not show a significant difference with cooking temperature and time, vacuum cooking method still could be an alternative to traditional cooking method in terms of better sensorial quality and healthier cooking conditions.

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