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Physicochemical and sensory properties of *sous vide* meat and meat analog products marinated and cooked at different temperature-time combinations

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ABSTRACT
Ready-to-eat (RTE) products elaborated from beef and meat analog, previously marinated (teriyaki and beer), were subjected to *sous vide* cooking at different combinations of temperature (70ºC and 80ºC) and time (60, 90 and 120 min for beef; 90, 120 and 150 min for meat analog). The *sous vide* cooking at 80ºC led to less cooking losses. The shear force values were approximately 50% lower in meat analog samples than in beef samples. The L^* and a^* value and sensory properties related to odor and color were similar in meat and meat analog products.

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sous vide; marinade; meat; meat analog; ready-to-eat

Introduction

The current lifestyle, which seeks to optimize time, has led the food industry to offer ready-to-eat (RTE) products, which are also innovative and healthy. Consequently, in recent years, the increase of RTE products has encouraged the application of new food processing technologies; among them, the *sous vide* cooking system,[1] which is a technique already known in the restaurant industry. Although some markets already have RTE products that have been cooked by *sous vide* technique, these products have not been expanded worldwide.[2]

The *sous vide* technique involves vacuum sealing food in a heat-sealable plastic bag, followed by incubation in a water bath at controlled conditions of low temperatures (53-81°C) and time.[3] Vacuum sealing has different benefits such as increasing the shelf life of food by minimizing the risk of recontamination during storage, inhibiting oxidation flavors and preventing the loss of volatile flavor and moisture compounds during the cooking process.[4] Moreover, this type of cooking differs from traditional cooking methods in two fundamental aspects: raw food is vacuum-sealed in thermostable plastic bags suitable for food quality and the product is cooked using a precisely controlled heat treatment.[4]

One of the potential applications of the *sous vide* technique is to obtain RTE products from meat, the demand for which has increased dramatically in recent years.[5] The application of heat treatment improves the palatability and microbiological stability of meat and meat products.[6,7] Therefore, the *sous vide* technique has become an interesting alternative to expand the current market of beef-based products.[8] The precise combination of temperature and time is a critical factor which affects the final quality characteristics of the meat cooked by *sous vide* processing.[9]

Animal diseases, a global shortage of animal protein, a strong demand for food meeting religious restrictions (halal and kosher), health concerns, and economic reasons have led to the increase of the consumption of vegetable proteins in food products over the last years.[10] Meat analog is similar to chemical characteristics and/or other sensory qualities such as texture, flavor, and appearance of specific types of meat.[11] It should be noted that the *sous vide* technique has not yet been studied in meat

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analogs, although it has been investigated in some plant derivatives. In green bean pods, this type of cooking technique has allowed a better organoleptic quality, conservation, and nutritional characteristics.[12] Likewise, the *sous vide* method has presented some advantages related to the conservation of nutritional quality and safety of cereals and legumes and the improvement of flavor.[13]

Moreover, in addition to the use of *sous vide* cooking, different techniques such as marinating can be used to improve the result of the cooking of meat products and their analogs. The method of marinating is a traditional culinary practice that has been used in order to improve the tenderness, flavor, and juiciness of beef,[14] as well as the tenderness and/or cooking performance of beef, pork and poultry.[15] Furthermore, most studies conducted with marinated products have focused on sensory analysis[16] or on microbiology.[17] However, there is limited knowledge about the effects of cooking conditions (temperature and time) on the physical characteristics (color and texture) of marinated protein-rich products (meat or meat analog).

Although there are several studies of *sous vide* treatment in vegetables, fish and meat,[2] no complete studies have been carried out in order to compare the physical and sensory parameters of RTE products elaborated from meat or meat analog, which have been previously marinated with different sauces, and then cooked using the *sous vide* technique with different combinations of time and temperature. Therefore, the aim of this work was to evaluate the effects of different temperature-time combinations of *sous vide* cooking on physicochemical and sensory parameters of the RTE products elaborated from beef and meat analog products previously marinated.

Materials and methods

Experimental design

Two RTE products from beef or meat analog, which had been previously marinated with two types of marinade (teriyaki or beer), were cooked by *sous vide* technique using different combinations of time and temperature. Thus, a full factorial design (2 × 2 × 3) was used, and the analyzed factors were: marinade type (teriyaki and beer), cooking temperature (70ºC and 80ºC), and cooking time (60, 90 and 120 min for beef; 90, 120 and 150 min for meat analog). Considering all variables (raw material, marinade, temperature and time cooking), 24 treatments were included in the experimental design. The experimental design was replicated twice.

The different cooking time studied for beef and meat analog should be noted. The cooking times for beef were selected from previous pilot studies where different cooking times (between 60 min and 120 min) were tested. However, the cooking times for meat analog were different and selected from previous pilot studies where various cooking times (between 45 min and 150 min) were tested. For meat analog, cooking times less than 90 min led to products which were not well-cooked products with an unsuitable texture for consumption. This can be explained due to the different thermal conductivity of meat and meat analog. The thermal conductivity of the beef depends on several factors (fat content, chopped size, etc.), and its value is around 0.63 (W/mK).[18] Moreover, although there is no information about the thermal conductivity of meat analog used in the present study, there are data of the thermal conductivity of the ingredients that are part of the meat analog, such as soy flour (0.05 W/mK), rice (0.15 W/mK) or kidney bean (0.15 W/mK),[18] lower values than those for beef, which implies that longer cooking times for meat analog are necessary in order to obtain the same degree of doneness in the final product.

Materials

Meat was obtained from beef skirt (*M. obliquus, transversus and rectus abdominis*) that was being marketed by a retail butcher's association. The meat was from Protected Geographic Indication (PGI) "Ternera de Navarra", which standardizes the animal origin and pre-mortem management. Beef skirt was chosen in order to improve the value of this meat cut, since the beef skirt has little value compared to others such as the loin, which is easily sold. The commercial meat analog Legumeat® Beef-Bean (SanyGran S.L., Navarre Spain), is a vegetable–based product, without food additives and made from flours of soy defatted, rice and bean. The Legumeat® Beef-Bean is a commercial product with texture similar to meat and a content of 46.8% of proteins, 11.2% of carbohydrates, and 1.6% of fats. It is a dehydrated product (Figure 1a), therefore before marinating, the dried samples were rehydrated with water (50:50) in 50ºC water for 12 h, followed by draining for 5 min (Figure 1b).

Two marinades, teriyaki and beer, were designed in order to marinate the beef or meat analog before cooking. These marinades differ in their composition and final flavor because it is sought to satisfy to different sectors of consumers. Previous pilot studies were necessary to obtain the final formulations of marinades used in the present study. The ingredients and the percentages of these marinades are shown in Table 1.

Preparation of *sous vide* meat and meat analog products

As previously explained in the experimental design, 24 different treatments were evaluated in the present study taking into account all variables: raw material (beef and meat analog), marinade type (teriyaki and beer), cooking temperature (70ºC and 80ºC), and cooking time (60, 90 and 120 min for beef; 90, 120 and 150 min for meat analog). Two batches were prepared, which means that the experimental design was replicated twice. For each batch, 1200 g approximately of beef and 1200 g approximately of meat analog were used and 24 samples (100 ± 10 g and 1 cm thick) were analyzed

Figure 1. Meat analog before (a) and after rehydration (b).

Table 1. Formulation of teriyaki and beer marinades.

Teriyaki marinade	%	Beer marinade	%
Pineapple juice	71.0	Lager type pale beer (4.8%, v/v)	79.9
Soy sauce	16.0	Orange marmalade	10.7
White wine (10%, v/v)	5.9	Sugar	7.8
Apple cider vinegar (5 º)	4.0	Mustard	1.2
Sugar	3.4	Salt	1.2
Salt	0.8	Ginger powder	0.1
Garlic powder	0.1	Garlic powder	0.3

(12 samples from beef and 12 samples from meat analog). Since two batches were prepared, as previously reported, two samples from each treatment were selected to undergo laboratory analyses.

Each sample (beef or meat analog) was marinated with the selected marinade (teriyaki or beer). The method used for marinating was by soaking the samples into the marinade for 30 min before cooking. After being marinated, the samples were packaged in polyamide-polypropylene pouches (90 μm of thickness) using the vacuum sealing machine Ghizzoni A-400 (Ghizzoni New Co, S.R.L., Reggio Emilia, Italy) in vacuum conditions (97%). Then, samples were cooked in the thermostatized water bath, SV-Thermo Top (Orved S.P.A., Venice, Italy), at different temperature-time combinations. The internal temperature was monitored using needle thermocouples. Once the cooking process had finished, the pouches were removed from the water bath and were cooled until they reached room temperature. Then, cooking loss, pH, instrumental color, instrumental texture, and sensory analysis were performed.

Cooking loss and pH measurement

The cooking loss was evaluated in duplicate. Cooking loss was calculated as weight loss divided by original weight, expressed as a percentage. The pH of raw, marinated and cooked samples was measured according to AOAC method 981.12.[19] All measurements were taken in quadruplicate using a pH meter (Sension+ PH1, HACH Lange Ltd, Manchester, UK).

Instrumental color measurement

Color was measured using a Minolta CM-2002 spectrophotometer (Konica Minolta Business Technologies Inc., Tokyo, Japan). Color readings were taken at five randomly selected non-overlapping points on the surface of each cooked sample. Sample color was measured in the CIELAB space,[20] with standard illuminant D65, observer angle 10º, and zero and white calibration. Lightness (L^*), redness (a^*), and yellowness (b^*) values were recorded, and the Chroma (C^*) and Hue angle (H^*) index values were calculated as $C = (a^{*2} + b^{*2})^{0.5}$ and $H = \arctan b^*/a^*$.

Instrumental texture analysis

Texture analyses were performed in a texturometer TA.XT Plus Texture Analyzer fitted with a 5 kg loadcell (Stable Micro Systems Ltd., Surrey, UK). The 2 kg weight was used to calibration. Shear force (SF) analysis on cooked samples (4 cm length × 1 cm width × 1 cm thickness) was performed using a Warner-Bratzler "V" slot blade for USDA Standard (model HDP/WBV), which sheared the samples at a constant speed of 1.7 mm/s and then pushed through the slot. In the beef samples, the "V" slot blade sheared the specimen perpendicularly to the muscle fibers. The maximum force (N) required to shear the sample was measured. Seven determinations were performed for each cooked sample.

Consumer hedonic evaluation

Seventy-three consumers (18 to 65 y; 44% female and 56% male) were recruited to participate in this study. The consumer hedonic evaluation was carried out using individual sensory booths at

Universidad Pública de Navarra. Considering the cooking loss and the textural properties and based on previous pilot studies, two different combinations of time and temperature of *sous vide* cooking were selected for beef and meat analog. The selected combinations were 70ºC – 90 min for beef, and 70ºC – 120 min for meat analog. Both products were evaluated with the two marinades (teriyaki and beer). Therefore, consumers evaluated four different products.

Samples were kept warm (40ºC) in a heater between 5 and 15 min until evaluation. Samples were given to consumers one at a time in an order that was established to avoid the effect of sample order presentation, first-order or carry-over effects.[21] Consumers ate unsalted toasted bread and drank mineral water to rinse their palate among samples. Each consumer evaluated, in a blind condition, liking of odor parameters (intensity, persistence, cooked meat, and overall odor), and liking of color parameters (intensity, homogeneity, and overall color) using 7-point hedonic category scales (1 = "dislike very much", 2 = "dislike moderately", 3 = "dislike slightly", 4 = "neither like nor dislike", 5 = "like slightly", 6 = "like moderately", and 7 = "like very much"). Firstly, odor parameters were assessed by the consumers under soft-red light (≈100 lux). Afterward, color parameters were assessed by the consumers under white light (≈450 lux).

Statistical analysis

Descriptive and inferential statistics were used according to procedures described by Anderson.[22] The Dixon's Q-test was applied in order to examine outlier values. A three-factors´ ANOVA was applied to evaluate the influence of the factors (marinade type, cooking temperature, and cooking time). Differences between two means were identified using an unpaired *t* Student test ($P < .05$). For multiple comparisons, Fisher´s Least Significant Difference (LSD) test was applied. The significance level was set at $P < .05$ in all cases. Discriminant analysis was performed to ascertain which of the instrumental parameters (pH, instrumental color and SF) were useful in differentiating among the beef and meat analog samples. Statistical analysis was carried out with Minitab® software (Version 18.1, Minitab Inc., PA, USA).

Results and discussion

Cooking loss

The effects of different combinations of temperature (70ºC and 80ºC) and time (60, 90 and 120 min for beef; 90, 120 and 150 min for meat analog) of *sous vide* cooking on cooking loss of the RTE products, which were elaborated from beef and meat analog previously marinated (teriyaki and beer), were studied. Table 2 shows the results obtained on the cooking loss of beef and meat analog products from experimental study. Cooking loss is an important parameter of meat cooked by *sous vide* technique since it is correlated with juiciness and yield of the final product. Beef samples were only significantly affected by the individual factors cooking time and cooking temperature ($P < .05$). The results for the cooking losses at temperatures of 70ºC and 80ºC were in the range of 5.11–8.17%, which were lower to those obtained by Botunestean et al.[23] for beef and Roldán et al.[24] for lamb. The difference of results can be explained because the variables, such as difference in sample size, heating schedule, and raw product history, affect the kinetics of weight and water loss.[25] Likewise, it should be noted that the marinating process improves the tenderness and cooking yield of beef, pork, and poultry.[15] According to Mozuriene et al.,[26] there is a positive effect of sour marinades on water capability, which can be correlated with swelling and/or increased extractiveness of myofibrillar proteins associated with an increase in ionic strength and a decrease in pH.[27–30]

There was an increase in weight losses as temperature rose ($P < .05$) for beef cooked by *sous vide* technique. The obtained results agree with those found by authors who used *sous vide* technique to cook beef,[8,31,32] pork,[9] or lamb.[24] Weight losses in cooked meat are caused because water can be evaporated due to increased temperature and/or reduced pressure. Furthermore, the water is retained by myofibrillar proteins within the muscle. At temperatures between 40 and 90ºC, the myofibrillar proteins are denatured

Table 2. Cooking loss (%) of beef and meat analog products cooked by *sous vide* technique.

Marinade	Temperature (ºC)	Cooking time (min)	Beef	Cooking time (min)	Meat analog
teriyaki	70	60	5.60 (0.13)[cd]	90	18.92 (5.11)[a]
		90	5.25 (0.16)[d]	120	11.27 (0.62)[a]
		120	6.14 (0.18)[bc]	150	12.11 (2.75)[a]
	80	60	5.95 (0.37)[cd]	90	2.79 (0.72)[b]
		90	6.90 (0.92)[ab]	120	5.64 (1.60)[b]
		120	7.39 (0.96)[a]	150	7.43 (2.06)[b]
beer	70	60	5.85 (0.38)[cd]	90	10.42 (0.04)[a]
		90	5.11 (0.32)[d]	120	15.37 (1.45)[a]
		120	6.48 (0.26)[bc]	150	14.49 (1.31)[a]
	80	60	5.62 (0.61)[cd]	90	4.41 (1.35)[b]
		90	7.64 (0.97)[ab]	120	5.87 (0.25)[b]
		120	8.17 (1.26)[a]	150	7.92 (2.02)[b]

Values are expressed as Mean (SD).
Different superscripts in the same column differ significantly ($P < 0.05$) by the Fisher's LSD multiple comparison test.

and shrinked.[32,33] Moreover, in the range of 56–62ºC the perimysial connective tissue is contracted,[34] what compress the muscle fiber bundles, encouraging water to be released from the meat cut.[35]

Regarding cooking time, the higher the time, the greater the water losses in beef samples ($P < .05$). These results are basically in accordance with those found by authors who used *sous vide* technique to cook beef,[32] pork[36] or lamb[24] and reported higher weight losses with longer cooking times at different temperatures.

Thus, water losses in the RTE products elaborated from beef previously marinated are the result of the temperature and time used. The vacuum sealing, carried out in the *sous vide* technique, of raw meat may cause lightly larger water losses due to the physical increase of pressure on the meat during vacuum packaging and the partial exudation of surface water resulting from the vacuum sealing of raw meat.[8] Likewise, it should be noted that, in addition to water, other water-soluble components are lost during cooking. The losses of these components are limited with the *sous vide* technique,[29] and if collagen solubilization temperature is achieved during cooking, after cooling, the soluble protein with the water and together with sarcoplasmic proteins form gelatin.[9]

The obtained results for meat analog showed that only the cooking temperature significantly affected cooking losses ($P < .05$). Conversely the obtained results for beef samples, there was a decrease in weight losses as temperature rose ($P < .05$) for meat analog cooked by *sous vide* technique, which can be explained by the different composition of beef and meat analog used. The meat analog product used in the present study is a mix formed by flours of soy, rice, and bean. The structure of this mix tends to create more open spaces in the sample structure, which could retain more water and decrease cooking loss as the temperature increases. Lin et al.[37] reported than cooking temperature was a significant factor for the water absorption capacity (WAC) and samples had the highest WAC at the highest cooking temperature in a soy protein-based meat analog. There is no information about cooking loss of meat analog products cooked by *sous vide* technique, therefore further studies would be necessary in order to investigate the thermal properties, protein solubility and protein structure of the meat analog.

At temperature of 70ºC, the cooking losses of meat analog ranged between 10.42% and 18.92%, higher values than those obtained for beef samples. Moreover, the results for the cooking losses of meat analog at temperatures of 80ºC were in the range of 2.79–7.92%, which were similar to those obtained for beef samples. Therefore, the products cooked at 80ºC could be considered the most acceptable treatments from an economic perspective, which implies less cooking losses. Likewise, these products would present greater juiciness due to a more concentrated retention of marinades, which is one of the advantages claimed by *sous vide* food cooking chefs.

pH changes

The pH values of beef and meat analog samples, raw and marinated, are shown in Table 3. The results of pH before marinating were 6.23 for beef and 6.21 for meat analog. Both types of marinade

Table 3. Changes in pH of beef and meat analog before and after marinating.

Treatment	Beef	Meat analog
Before marinating	6.23 (0.50)^{a}	6.21 (0.17)^{a}
After marinating with teriyaki	4.67 (0.22)^{c}	5.54 (0.26)^{c}
After marinating with beer	5.00 (0.15)^{b}	5.92 (0.13)^{b}

Values are expressed as Mean (SD).
Different superscripts in the same column differ significantly (P < 0.05) by the Fisher's LSD multiple comparison test.

decreased pH values significantly (P < .05) for beef and meat analog due to their content of acids. Taking into account that the water-binding properties of meat increase at pH values above or below the meat isoelectric point,[38] the teriyaki marinade would be recommended because it led to the lowest pH values in marinated beef (4.67). Likewise, in meat analog, the teriyaki marinade decreased the pH value more than the beer marinade did. It should be noted that the change of pH after marinating process was similar for both products.

Table 4 reports the pH values for the RTE products elaborated from beef and meat analog products marinated (teriyaki and beer) and cooked with different combinations of temperature (70ºC and 80ºC) and time (60, 90 and 120 min for beef; 90, 120 and 150 min for meat analog) of *sous vide* technique. Cooked samples were significantly affected by the triple interaction among marinade type, cooking temperature, and cooking time (P < .05). The results for the pH were in the range of 5.19–6.17 for beef, and 5.68–6.08 for meat analog, higher pH values than those obtained after marinating. This increase of pH in marinated meat products after cooking was reported by Ergercer &Gokce[39] for turkey breast. These results can be explained because during the cooking, the available carboxylic groups of proteins are reduced and the calcium and magnesium ions are released from proteins.[40] In the present study, the cooking process increased the pH values in beef and meat analog, therefore the meat and vegetable proteins have behaved the same.

Color stability

The effects of different temperature-time combinations (cooking temperature: 70ºC and 80ºC; and cooking time: 60, 90 and 120 min) of *sous vide* cooking on instrumental color parameters (lightness, L^*; redness, a^*; yellowness b^*; Chroma, C^*; and Hue angle H^*) were evaluated in the RTE products elaborated from beef previously marinated (marinade type: teriyaki and beer). It should be noted that Table 5 shows the obtained results in the RTE product, which is the cooked beef previously marinated. Likewise, since the objective of the study was to evaluate the effects of different temperature-time combinations of *sous vide* cooking and the meat was from PGI "Ternera de Navarra", which standardizes the animal origin and pre-mortem management, more information

Table 4. Changes in pH of beef and meat analog products cooked by *sous vide* technique.

Marinade	Temperature (ºC)	Cooking time (min)	Beef	Cooking time (min)	Meat analog
teriyaki	70	60	6.15 (0.59)^{a}	90	6.08 (0.24)^{a}
		90	5.88 (0.35)^{b}	120	5.99 (0.14)^{ab}
		120	5.73 (0.08)^{bc}	150	5.98 (0.11)^{b}
	80	60	5.19 (0.05)^{d}	90	5.68 (0.04)^{bcd}
		90	5.63 (0.36)^{bc}	120	5.82 (0.04)^{d}
		120	6.17 (0.44)^{a}	150	5.83 (0.14)^{cd}
beer	70	60	5.67 (0.02)^{bc}	90	5.85 (0.11)^{cd}
		90	5.68 (0.02)^{bc}	120	5.91 (0.02)^{cd}
		120	5.68 (0.02)^{bc}	150	5.94 (0.05)^{bcd}
	80	60	5.58 (0.11)^{c}	90	5.91 (0.05)^{d}
		90	5.80 (0.07)^{bc}	120	5.90 (0.03)^{bcd}
		120	5.78 (0.02)^{bc}	150	5.90 (0.01)^{bcd}

Values are expressed as Mean (SD).
Different superscripts in the same column differ significantly (P < 0.05) by the Fisher's LSD multiple comparison test.

Table 5. Color parameters (L^*, lightness; a^*, redness; b^*, yellowness; C^*, Chroma; H^*, Hue angle) of beef cooked by *sous vide* technique.

Marinade	Temperature (ºC)	Time (min)	L^*	a^*	b^*	C^*	H^*
teriyaki	70	60	47.2(6.8)^{def}	9.7(0.5)^{cde}	14.0(1.9)^{d}	17.0(1.4)^{de}	54.9(4.8)^{cd}
		90	46.3(3.0)^{defg}	10.2(1.5)^{bcd}	15.6(1.6)^{bc}	18.6(2.0)^{bcde}	57.0(2.3)^{bc}
		120	45.2(3.6)^{efg}	10.8(1.6)^{abc}	14.9(0.5)^{cd}	18.4(1.0)^{bcde}	54.2(4.4)^{cd}
	80	60	49.3(6.4)^{cde}	8.3(1.1)^{f}	14.0(1.2)^{d}	16.7(0.9)^{e}	59.3(4.5)^{ab}
		90	50.6(6.2)^{bcd}	9.9(1.6)^{cde}	15.1(1.2)^{cd}	17.6(1.8)^{cde}	59.7(7.2)^{ab}
		120	53.5(3.4)^{abc}	9.3(0.5)^{def}	16.0(0.9)^{abc}	18.5(1.0)^{bcde}	59.5(1.0)^{ab}
beer	70	60	44.2(4.0)^{fg}	11.4(1.3)ab	14.9(1.4)^{cd}	18.8(1.4)^{bcd}	52.6(3.8)^{d}
		90	44.6(4.8)^{efg}	11.7(0.9)a	15.9(1.0)^{abc}	19.7(0.7)^{bc}	54.0(3.2)^{cd}
		120	42.2(4.9)^{g}	11.8(0.7)a	16.6(1.4)^{ab}	20.4(1.3)^{b}	54.6(2.3)^{cd}
	80	60	54.4(4.9)^{ab}	9.2(0.8)^{def}	15.1(2.4)^{cd}	17.8(2.1)^{cd}e	58.3(4.4)^{bc}
		90	53.8(3.7)^{abc}	10.7(1.7)^{abc}	17.1(1.8)^{a}	24.8(6.8)^{a}	63.0(3.8)^{a}
		120	55.9(4.3)^{a}	8.8(2.0)^{ef}	17.2(1.4)^{a}	19.4(1.1)^{bc}	62.8(6.5)^{a}

Values are expressed as Mean (SD).
Different superscripts in the same column differ significantly ($P < 0.05$) by the Fisher's LSD multiple comparison test.

related to the raw beef color has not been considered relevant to be included. Regarding lightness, beef samples were significantly affected by cooking temperature and by the interaction between this parameter and marinade type ($P < .05$). The samples cooked at 70ºC had lower L^* values than those cooked at 80ºC because higher cooking temperature leads to higher denaturation and aggregation of sarcoplasmic and myofibrillar proteins which might increase light scattering.[36,41] Likewise, a darker meat appearance can be due to higher moisture content in meat cooked at lower temperature, which would lead to a deeper penetration of light in the tissue.[42] In this sense, as previously reported, in the present study, the beef samples cooked at 70ºC had lower cooking losses than those cooked at 80ºC. The higher L^* values obtained in beef cooked at 80ºC in the present study leads to lighter color of the beef, which is desirable in meat products in order to ensure high consumer acceptance.[5]

Concerning redness (a^*), beef samples were significantly affected by cooking temperature, cooking time, marinade type and by the interaction between cooking temperature and cooking time ($P < .05$). Redness intensity in cooked meat is inversely related to the degree of denatured myoglobin, a denaturing process which takes place between 55ºC and 65ºC although continues till 75ºC or 80ºC.[43] Consequently, beef samples cooked at 70ºC revealed a more intense-red color (higher a^* values) than those cooked at 80ºC ($P < .001$), what indicates higher myoglobin degradation as cooking temperature increased. These results were supported by García-Segovia et al.,[8] who cooked beef samples at 60ºC – 80ºC for 15–60 min, and Roldán et al.,[24] who cooked lamb samples at 60ºC – 70ºC – 80ºC for 6 – 12 – 24 h.

Chroma or meat color saturation is affected by the concentration of myoglobin and its degree of denaturation, being more predominant with greater concentrations of myoglobin and at a lower rate of denatured myoglobin.[44] Beef samples were significantly affected by the triple interaction among cooking temperature, marinade type and cooking time ($P < .05$) and the Chroma values showed unclear tendency.

Hue angle (H^*) is related to the chemical state of the myoglobin and it is inversely related to the a^* values. Therefore, beef samples cooked at 70ºC showed lower H^* values than those cooked at 80ºC ($P > .05$), which could be explained by the lesser degree of myoglobin denaturation mentioned above.

There was a significant increase of b^* values as a consequence of cooking time ($P < .001$), which was most likely due to the formation of metmyoglobin and further heat-denaturation of this protein, giving rise to a brownish color. Higher b^* values as a consequence of increasing *sous vide* cooking time have also been detected by other studies,[24] where *sous vide* cooked lamb samples were analyzed. Moreover, regarding marinade type, the samples marinated with beer marinade showed lower b^* values than those cooked with teriyaki marinade ($P < .001$), which could be explained by the color of the beer marinade.

Moreover, it should be highlighted that using the *sous vide* cooking can reduce degradation of myoglobin in beef.[32] Likewise, there was an increase in redness of pig cheeks cooked by *sous vide* cooking as compared to those cooked in air-filled packages.[9] According to Mancini,[45] deoxymyoglobin has higher thermostability than oxy- and metmyoglobin, which implies that vacuum packaging increases the contribution of myoglobin redox form in meat. Thus, using *sous vide* technique can limit the oxidation of myoglobin and increase its thermal stability,[29] which would be an advantage for chefs, because in addition to control the core temperature of the meat during the cooking, it would minimize changes in a^* and limit the reduction in its redness if it is compared with other methods of cooking. Therefore, other potential effect of *sous vide* cooking at moderate temperature, compared with conventional cooking, would be different color characteristics due to a different development of the Maillard reaction on the meat surface, combined with a different extent of myoglobin denaturation.[8,9]

Table 6 displays the obtained instrumental color parameters in lightness (L^*), redness (a^*), yellowness (b^*), Chroma (C^*) and Hue (H^*) in the RTE products elaborated from meat analog products cooked under the different experimental conditions studied (marinade type: teriyaki and beer; cooking temperature: 70ºC and 80ºC; and cooking time: 90, 120 and 150 min). Regarding lightness, meat analog samples were significantly affected by cooking temperature, cooking time, marinade type and by the interaction between cooking time and cooking temperature ($P < .05$). Meat analog samples, previously marinated with teriyaki, cooked at 80ºC showed lower L^* values than those samples cooked at 70ºC. These results could be explained by the higher moisture content in meat analog cooked at higher temperature, which would lead to a deeper penetration of light in the sample. In this sense, as previously reported, in the present study, the meat analog samples cooked at 70ºC had higher cooking losses than those cooked at 80ºC.

Concerning redness, meat analog samples were significantly affected by cooking temperature and by the interaction between cooking temperature and marinade type ($P < .05$). Likewise, the meat analog samples marinated with teriyaki marinade and cooked at 70ºC had lower a^* values than those cooked at 80ºC. Chroma or color saturation was affected by the marinade type ($P < .001$) and samples marinated with beer marinade showed lower C^* values than those marinated with teriyaki marinade. Regarding Hue angle (H^*), meat analog samples were significantly affected by the triple interaction among cooking temperature, marinade type and cooking time ($P < .05$) and the Chroma H^* values showed unclear tendency.

Concerning yellowness, meat analog samples were significantly affected by cooking time, marinade type and by the interactions between cooking temperature and cooking time and between cooking temperature and marinade type ($P < .05$). The meat analog samples marinated with beer marinade showed lower b^* values than those cooked with teriyaki marinade ($P < .001$) due to the color of the beer marinade. As previously explained, the same effect of beer marinade on the b^* values was observed for beef samples of the present study. Moreover, the b^* values were lower as increasing time cooking.

There is lack of research related to meat analog products cooked by *sous vide* technique, therefore the obtained results for meat analog only have been compared with the color parameters of beef products of the present study. It can be highlighted that the b^*, C^* and H^* values were higher in meat analog samples than in beef samples. However, the L^* and a^* values were similar in both products (beef *vs.* meat analog).

Table 6. Color parameters (L^*, lightness; a^*, redness; b^*, yellowness; C^*, Chroma; H^*, Hue angle) of meat analog cooked by *sous vide* technique.

Marinade	Temperature (ºC)	Time (min)	L^*	a^*	b^*	C^*	H^*
teriyaki	70	90	59.2(3.5)^{ab}	9.1(0.7)^{de}	25.5(4.3)$_{a}$	27.1(3.9)^{a}	69.9(3.9)^{a}
		120	57.2(1.5)^{abc}	10.1(0.6)^{bcd}	22.8(1.3)^{bcd}	24.9(1.5)^{bcd}	66.4(0.2)^{bc}
		150	59.9(3.7)^{a}	8.7(1.9)^{e}	25.6(2.4)^{a}	27.2(1.9)^{a}	71.0(5.4)^{a}
	80	90	55.3(2.7)^{cde}	10.4(1.0)^{abc}	24.3(2.0)^{ab}	26.4(2.2)^{ab}	66.9(0.6)^{b}
		120	53.2(2.3)^{e}	11.0(0.7)^{a}	23.8(1.2)^{abc}	26.2(1.3)^{ab}	65.2(1.2)^{bcd}
		150	52.9(3.1)^{e}	10.9(0.6)^{ab}	22.3(0.9)^{cd}	25.6(2.1)^{abc}	64.0(0.8)^{d}
beer	70	90	54.6(2.6)^{cde}	10.3(0.5)^{abc}	22.5(0.9)^{bcd}	24.7(1.0)^{bcd}	65.4(3.9)^{bcd}
		120	54.0(2.5)^{de}	10.1(0.6)^{bc}	21.7(1.1)^{d}	23.8(1.1)^{cd}	65.1(0.2)^{bcd}
		150	53.9(3.5)^{de}	10.2(0.4)^{abc}	21.3(1.1)^{d}	23.6(0.7)^{d}	64.3(5.4)^{cd}
	80	90	56.6(2.2)^{bcd}	9.8(0.8)^{cd}	22.1(1.3)^{cd}	24.2(1.5)^{cd}	66.2(0.6)^{bc}
		120	52.5(3.8)^{e}	10.2(1.3)^{abc}	21.8(1.8)^{d}	24.9(1.5)^{cd}	64.9(1.2)^{bcd}
		150	55.0(2.0)^{cde}	10.1(0.7)^{abc}	21.3(1.1)^{d}	23.5(1.3)^{d}	64.5(0.8)^{cd}

Values are expressed as Mean (SD).
Different superscripts in the same column differ significantly ($P < 0.05$) by the Fisher's LSD multiple comparison test.

It should be taken into account that the redness parameter is the characteristic color parameter for meat products. Therefore, these results could imply a similar appearance between beef and meat analog cooked by *sous vide* technique. These results would be positive for meat analog products as the appearance is one of the most important attributes associated with consumer acceptance of *sous vide* beef products.[46] Likewise, for practical purposes, this finding may prove quite interesting, as chefs can value the fact that raw material (beef or meat analog) will not affect the reddish color of the RTE products cooked by *sous vide* method at moderate temperatures (70 or 80ºC) during moderate time (60–150 min).

Instrumental texture analysis

Texture, like color, is a very important parameter of food quality and affects the acceptance of RTE products among consumers. Thus, the effects of different combinations of temperature (70ºC and 80ºC) and time (60, 90 and 120 min for beef; 90, 120 and 150 min for meat analog) of *sous vide* cooking on SF of the RTE products elaborated from beef and meat analog previously marinated (teriyaki and beer) were studied. The obtained values for SF of the RTE products are shown in Table 7. In spite of the fact that the different samples of meat came from the same farm, animal part (beef skirt) and aging time, the parameters and conditions of the marinade and cooking process were controlled, and the final RTE products were uniform, some high standard deviation values for SF (Table 7) were obtained. These results could be attributable to the variations of the raw samples (before marinating and cooking process) between the two batches used. High variations for SF have been reported previously by García-Segovia et al.[8] in raw beef by using Warner–Bratzler SF measurement.

Beef samples were significantly affected by the triple interaction among cooking temperature, marinade type and cooking time ($P < .05$). Likewise, the rest of double interactions and individual factors were significant ($P < .05$). The SF in meat is a good measure of initial bite tenderness, whose changes during cooking process are related to heat-induced alteration of myofibrillar proteins and connective tissue, as heat solubilizes the connective tissue leading to meat tenderization, while denaturation of myofibrillar proteins causes meat toughening.[47] Consequently, beef samples cooked at 70ºC showed more toughness (higher SF values) than those cooked at 80ºC ($P < .05$), because in *sous vide* cooking, heat in conjunction with the moist in-pack environment solubilizes the connective tissue leading to meat tenderization. This behavior has been described by other authors such as Vaudagna et al.,[32] who reported decreases of SF values as the treatment temperature was raised from 50 to 65ºC in *sous vide* cooked beef muscles, and García-Segovia et al.,[8] who observed toughness decreases with *sous vide* cooking from 60 to 80ºC in beef. However, it should be noted that in the present study, toughness decreases from 70 to 80ºC were not observed for beef marinated with teriyaki and cooked for long times (90 and 120 min). These results could be explained by the composition of the teriyaki marinade and its lower pH that can lead to different changes in textural properties of beef. Therefore, further research would be necessary to explain this different behavior of beef previously marinated with teriyaki.

Table 7. Changes in shear force (N) of beef and meat analog cooked by *sous vide* technique.

Marinade	Temperature (ºC)	Time (min)	Beef	Time (min)	Meat analog
teriyaki	70	60	46.3(10.8)^{ab}	90	17.5(4.5)^{cde}
		90	32.7(8.2)^{de}	120	18.1(3.0)^{cde}
		120	37.1(8.4)^{cd}	150	24.1(6.4)^{ab}
	80	60	30.8(8.0)^{cd}	90	21.1(3.3)^{bcd}
		90	51.4(5.2)^{a}	120	28.4(6.9)^{a}
		120	42.9(10.9)^{bc}	150	16.3(4.0)^{de}
beer	70	60	48.9(11.1)^{ab}	90	28.7(7.1)^{a}
		90	49.0(8.9)^{ab}	120	15.2(2.9)^{e}
		120	31.3(7.9)^{de}	150	17.7(4.6)^{cde}
	80	60	37.5(9.7)^{cd}	90	22.7(5.1)^{bc}
		90	37.2(8.7)^{cd}	120	20.5(5.1)^{bcd}
		120	26.8(6.1)^{e}	150	25.5(6.4)^{ab}

Values are expressed as Mean (SD).
Different superscripts in the same column differ significantly ($P < 0.05$) by the Fisher's LSD multiple comparison test.

Moreover, it should be highlighted the positive effects of meat marinated for consumers, who look for RTE products easy to bite and chew. If meat is marinated in an acid solution, the pH will decrease and, consequently, protein hydration and tenderness will increase significantly.[27,29] Likewise, acidic environment leads to decreases of hardness in connective tissues due to the weakening electrostatic interactions between myofibrillar protein chains or enzymatic mechanisms.[48] Therefore, in terms of applicability, in the RTE products elaborated from beef, the positive effect of the process (marinating and *sous vide* cooking) on meat texture claimed by chefs has to do with the type of marinate used, which leads to decreases in pH, and the adequate combination of time and temperature, which leads to the degradation of the muscle connective tissue.

Regarding the meat analog samples cooked by *sous vide* technique, although the parameters and conditions of the marinade and cooking process were controlled and it was used a low-weight load cell in the texturometer that leads to more sensibility in the measures, some high standard deviation values for SF (Table 7) were obtained. As previously explained for the high standard deviation values for SF found in beef samples, these results could be attributable to the variations of the raw samples (before marinating and cooking process) between the two batches used.

Meat analog samples were significantly affected by the triple interaction among cooking temperature, marinade type and cooking time ($P < .05$) and the SF values showed unclear tendency. The obtained results for meat analog only have been compared with the SF parameter of beef samples of the present study because there is a lack of research related to meat analog products cooked by *sous vide* technique. It can be highlighted that the SF values were approximately 50% lower in meat analog samples than in beef samples. These results could be explained by the different source of proteins of each product: vegetable proteins in meat analog samples, and animal proteins in beef samples. Meat analogs have a striated, layered structure similar to muscle meat, and they may contain textured proteins (such as textured soy flour and concentrates), in order to provide texture, mouth feel, appearance and bind water, and nontextured proteins (such as soy-protein concentrates and isolated soy proteins, wheat gluten, whey protein, and so on) in order to help with fat and water retention, emulsification, protein fortification and nutrition.[11] Moreover, the myofibrillar protein from meat exhibits different biochemical and rheological characteristics and forms gels due to the distribution of the myosin isoforms.[49] It should be noted that texture is one of the most important keys to success for meat analogs and one of the biggest challenges for the researchers, therefore further studies would be necessary in order to obtain texture more similar to meat products. However, in spite of the obtained results for meat analog, lower SF values than in beef samples, these could be considered as positive results because softer tenderness can be more positively valued by consumers with specific characteristics such as elderly and children, encouraging them to the required protein consumption.

Sensory evaluation

The food cooked by *sous vide* technique is considered by consumers as products with high gastronomy quality,[2] therefore the evaluation of sensory parameters is very important. Energy consumption is an important parameter to consider in the selection of the combination of temperature and time for the cooking treatment. As previously reported in material and methods sections, the combinations 70°C – 90 min for beef and 70°C – 120 min for meat analog were selected for the sensory evaluation. Figures 2 and 3 show the obtained sensory parameters in odor (intensity, persistence, cooked meat and global) and color (intensity, homogeneity and global) in beef and meat analog samples cooked under the temperature/time cooking combinations selected.

There were no significant differences for odor parameters of intensity, persistence and global ($P > .05$) (Figure 2). Likewise, the scores of the odor parameter "cooked meat" were higher in beef than in meat analog samples ($P < .05$), independently the marinade type used. Regarding color parameters, there were no significant differences for intensity and global color ($P > .05$) (Figure 3). Moreover, the homogeneity color scores were higher in meat analog than in beef samples ($P < .05$), independently the marinade type used. This result could be explained because the meat analog product used in the present study is a commercial product, which is a mix of flours (defatted soy, rice, and bean), while the beef used is a heterogeneous muscle.

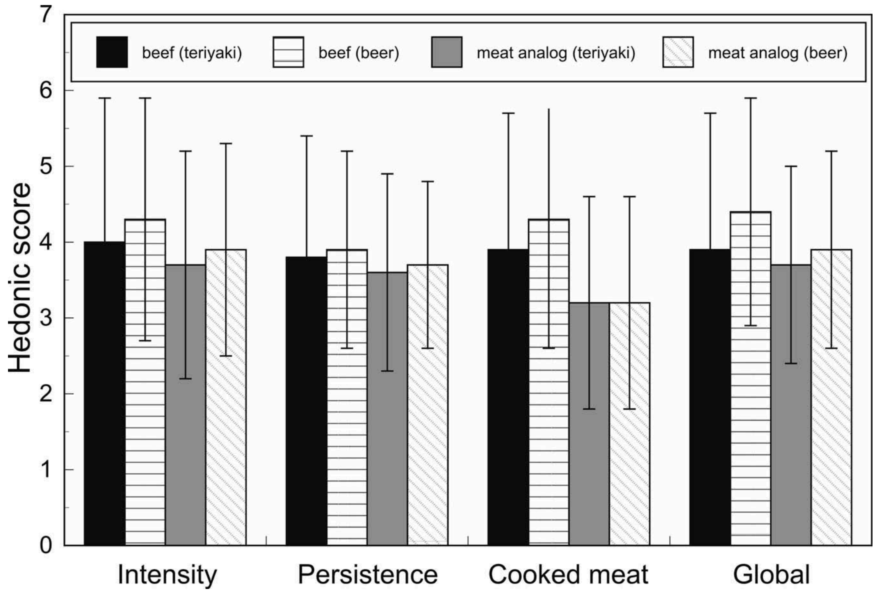

Figure 2. Sensory evaluation of odor parameters for beef and meat analog cooked by *sous vide* technique. Error bars indicate standard deviation.

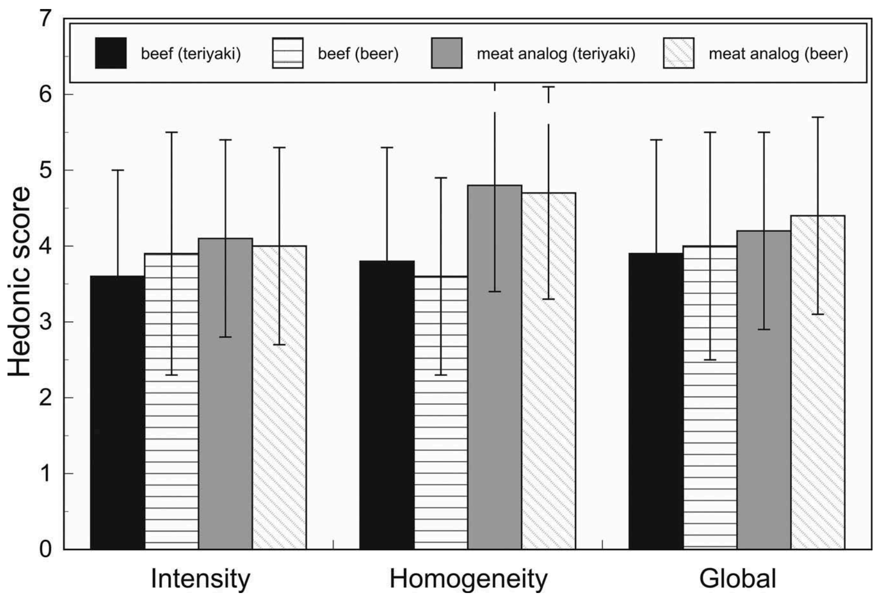

Figure 3. Sensory evaluation of color parameters for beef and meat analog cooked by *sous vide* technique. Error bars indicate standard deviation.

The odor and color parameters were valued around 4, that is, "Neither like nor dislike". These results could be optimized by reformulation of marinade type used and new combination of temperature/time cooking. Moreover, the color, juiciness, and tenderness are the main sensory properties of beef, which determine the meat quality.[50] However, in the present study, the textural and flavor parameters were not included in the consumer test due to food safety issues. Therefore, further studies would be necessary in order to set the formulations of marinade and the combination of temperature/time cooking that lead to higher scores in sensory parameters, including parameters related to textural and flavor properties. In the present study, it has been found that a meat analog cooked by *sous vide* technique has similarities in attributes related to odor and color, compared to a beef, regardless of the marinade type used. Therefore, these findings would be interesting for food industry and many top-level restaurant chefs, who are using *sous vide* cooking due to its ease and appropriateness for the management of RTE food products, because they could fulfill with the expectations of new consumers who look for plant-based foodstuffs with traditional sensory characteristics.

Discriminant analysis

Discriminant analysis was employed in an attempt to differentiate between the two types of products (beef *vs*. meat analog) and based on instrumental variables analyzed. Seven functions were generated by the analysis. Discriminant function F1 explained 89.4% of the variance and was most closely associated with the pH variable. Discriminant function F2 explained 3.2% of the variance and was associated with a^* and L^* parameters. Function F3 just explained 2.8% of the variance and H^* and C^* parameters were involved. Applying the first two functions to the instrumental variables, the scatterplot depicted in Figure 4 was yielded. The meat analog samples were grouped into a narrow

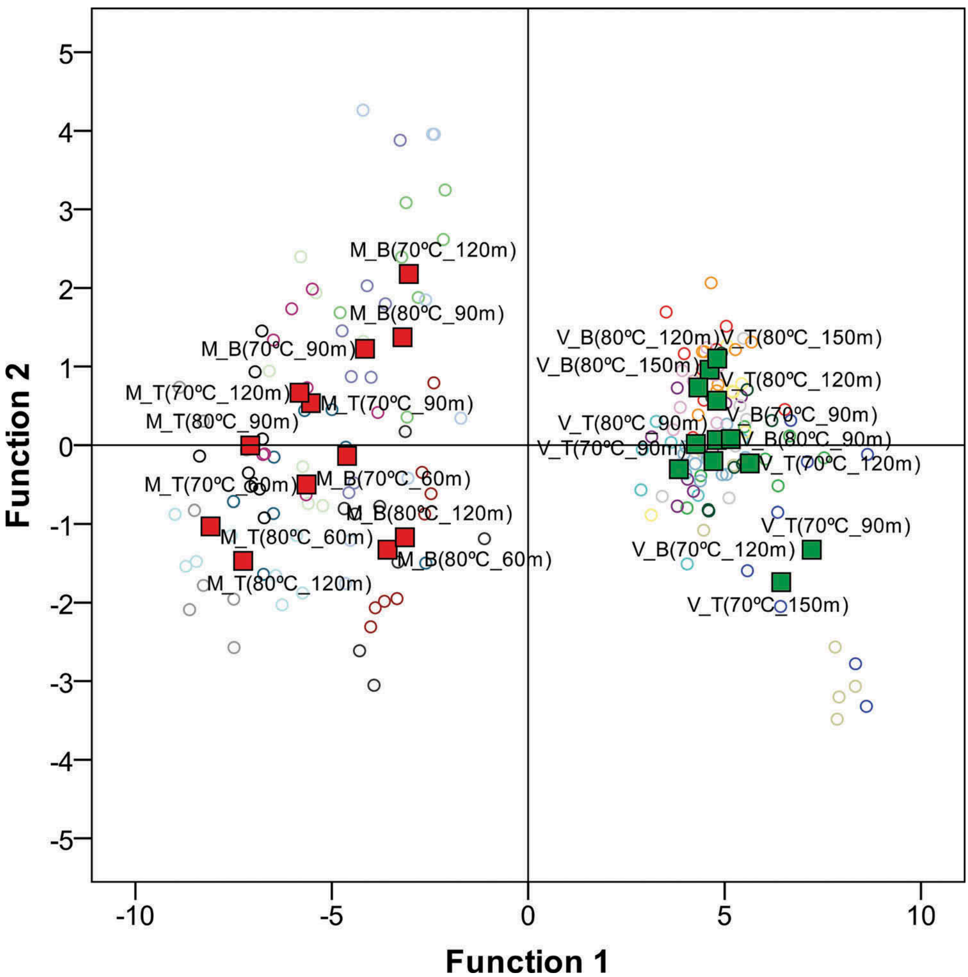

Figure 4. Plot of the canonical discriminant functions for the instrumental parameters used in characterization of beef (M) and meat analog (V) previously marinated (B: beer; T: teriyaki) and cooked by *sous vide* technique at different combinations of temperature (70°C and 80°C) and time (60, 90 and 120 min for beef; 90, 120 and 150 min for meat analog).

cluster, while the beef samples were grouped into a scattered cluster. Therefore, pH, a^* and L^* were enough to characterize these RTE products cooked by *sous vide* technique.

Conclusion

The obtained results show the applicability of the marinating and *sous vide* cooking techniques in the elaboration of RTE products from beef or meat analogs, which implies new opportunities for their application beyond their current use in the food industry. Moreover, this study demonstrates the potential of meat analog products, which in addition to being a source of proteins, can lead to products with similar physical and sensory properties to those from beef. Although further studies would be necessary to evaluate the effect on nutritional quality and consumer acceptance in both RTE products (beef and meat analog), taking into account the obtained results in this study, meat analog products could be considered as a viable alternative for meat products and open new commercial opportunities for their use in the elaboration of RTE products. This study emphasizes the feasibility of using the combination of marinating and *sous vide* cooking techniques to yield new RTE products with high protein content from meat or meat analog and without negatively affecting quality characteristics.

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