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EFFECT OF TUMBLING TIME, INJECTION RATE AND K-CARRAGEENAN ADDITION ON PROCESSING, TEXTURAL AND COLOR CHARACTERISTICS OF PORK *BICEPS FEMORIS* MUSCLE

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The effect of tumbling time (0-9 hours), injection rate (20-50%) and k-carrageenan addition (0.25 - 0.5%) on quality characteristics of cooked pork *Biceps femoris* muscle have been studied. Properties of injected and tumbled meat samples were determined by measuring processing characteristics (tumbling yield, cooking yield and expressible moisture), color (L*, a*, b*, Hue angle and Chroma) and texture (firmness, toughness, adhesiveness, work of adhesion and fracturability). Increasing tumbling time up to 9 h led to better hydration properties and increased the cooking yield for all samples, both with 0.25% and 0.5% of k-carrageenan addition. It also decreased the firmness and toughness of the evaluated samples. *Biceps femoris* samples containing a higher level of k-carrageenan were tenderer than those containing less polysaccharide. Neither injection rate nor tumbling time affected the color components of the analyzed samples.

Keywords: *Biceps femoris*, tumbling time, injection rate, k-carragenan, cooking yield, texture, color

Introduction

Meat is a basic food for human nutrition, being the main source of protein for the human body. Meat handling and processing directly affect product quality and consumers' health. Nowadays we have, on the one hand, producers who with different recipes and various technologies aim at increasing as much as possible the weight of meat in a less processing time, and on the other hand consumers who demand quality products, containing as much meat as possible at acceptable prices.

Water is the major compound of meat (about 70 g/100 g for lean meat) and the ability of a product to retain the natural and added water is very important from the economical point of view. It was estimated that over 50% of processed pork has unacceptable water loss (Kauffman *et al*., 1992; Stetzer & McKeith, 2003). For whole muscle products, increasing water holding capacity is different from the restructured meat products. Also small injection rates were studied in most existent surveys (10-18%) while in industry quantities over 50% injection rates are used. Furthermore, Shackelford *et al*., (1995) stated that many workers observed that slaughtered muscles vary in texture and in structure. This phenomenon was observed by other researches too (Payne *et al*., 1992; Karlson *et al*., 1993; Wiklund *et al*., 1998). Normally, the entire technological process significantly affects the final product, but even minor changes in the process can result in changes in the quality of the finished product (Hullberg *et al*., 2005). Besides, different types of muscles gained different degrees of tenderness after the same treatment (Lachowicz *et al*., 2003). Often injection is followed by tumbling in order to achieve a better hydration and to ensure formation of binding material. Hullberg *et al*. (2005) reported that including tumbling in the meat processing resulted in a more uniform distribution of the brine and a more homogeneous cured color distribution. Tumbling process favorably influenced rehydration process for salt-cured cod (Bjorkevoll *et al*., 2004).

In order to retain as much added water as possible during cooking, proper water-binding compounds must be added to the injectable brine. Thus, sodium chloride, sodium phosphates, sodium lactate, polysaccharide gums, hydrolyzed soy or whey proteins, and modified starch are common ingredients to meet the functional needs (Xiong, 2005). Polysaccharides or hydrocolloids derived from a variety of plants and microorganisms are used extensively as ingredients in a number of ground, restructured or whole meat products, to contribute to desirable binding characteristics, texture and appearance of the finished products (*Chin et al*., 1998; Perez-Mateos *et al*., 2000).

K-carrageenan is a linear sulphated polysaccharide extracted from red seaweeds. Its idealized structure is a repeating disaccharide sequence of *β*-D-galactopyranose-4-sulphate residues linked 1,3- and 3,6-anhydro-*α*-D-galactopyranose residues linked through positions 1,4. (Wang *et al*., 2005; Tomšic, 2008). It is widely used in the food industry due to its water-binding, thickening and gelling capacities. For instance, in “ham-like” products, k-carrageenan is used to improve water retention, yield, texture and juiciness (Imeson, 2000). In these products, carrageenan’s success is achieved by its low viscosity when dispersed in brine, hydration during heat treatment and jellifying during cooling (Pietrasik, 2003). It was also reported to favor hydration properties and thermal stability of pork gels (Pitrasik, & Jarmoluk, 2003). Verbeken *et al*., (2005) observed that k-carrageenan addition up to 2% led to an increase of water holding capacity of meat gels. Hsu and Chung (2001) stated that adding up to 2% k-carrageenan increased cooking yield hardness and other textural parameters for low-fat emulsified meatballs. Ivanovic *et al*. (2002) found that adding carrageenan to smoked pork loin in low concentrations (0.25%, 0.4% and 0.55%) reduced significantly mass losses during thermal treatment and increased product firmness.

The primordial factor that determines the consumers' choice is the product appearance. Color is also a major factor of meat aspect. Recently, objective evaluation of color for different foods was performed using computer programs. They have the advantage over ordinary colorimeters to analyze each image pixel individually, while being inexpensive (Brosnan & Sun, 2004; Du & Sun, 2004; Yam & Papadakis, 2004). For many surveys, color had been analyzed using this technique (Papadakis *et al*., 2000; O'Sullivan *et al*., 2003; Mendoza, 2004; Pedreschi *et al*., 2004; Pedreschi *et al*., 2005; Leon *et al*., 2006; Laurent *et al*., 2010; Larrain *et al*., 2008; Valous *et al*., 2010).

The main objective of this study was to evaluate the effect of k-carrageenan addition, injection rates and tumbling time on pork *Biceps femoris* technological and sensory characteristics. For this, the effect of different percent of brine with polysaccharide addition combined with tumbling time on technological, textural and color parameters of processed meat was analyzed.

Materials and methods

Sample preparation

Raw material

The pork *Biceps femoris* muscle analyzed in the present study is a large muscle localized on the lateral part of the ham.

The fresh *Biceps femoris* muscles were removed from pork carcasses 24 hours after slaughtering, over a 6- month period. Every muscle had a medium weight of 2.5kg±0.1kg. Muscles were collected from both sides of pork carcass, sealed in plastic bags and handled in refrigeration conditions at +4˚C. Samples were processed within maximum two hours after collecting. The initial medium pH of raw meat was 6.12 ± 0.07. Every time muscles were sliced into pieces of 100 g chops per loin, marked with cotton fiber of different colors for differentiation and weighted (obtaining the raw weight).

Tumbling

The tumbling process was conducted in a laboratory small capacity tumbler (Reveo Marivac, USA) at a vacuum of 85 MPa with a drum speed of 14 rpm. Samples were tumbled intermittently (20 min on, 10 min of), at 4°C for 9 h summarizing a total of 5040 rotations. After every hour of tumbling, three samples were collected for analyses (two for heat treatment and one for other analyses). To counteract a substantial reduction of the total ham weight in the drum because of sampling, the drum contents were supplemented each time with ballistic gel cuts sealed in polyethylene bags in order to avoid interactions with meat.

Cooking procedure

After each hour of tumbling, samples were collected from the drum and weighed (obtaining the green meat weight). In order to perform heat treatment, samples were placed in glass containers (one sample per container). After that samples were immersed in a water bath (MEMMERT, WNB-45, Germany) gradually increasing water temperature by ~1.5°C per min from 20°C ± 2°C to 75°C until the internal temperature of the sample reached 72°C, measured with a thermocouple. After heat treatment, the samples were cooled down in running water to about 20°C and weighed (obtaining the cooked weight).

Methods

Brine injection

Brine used for injection contained sodium chloride, sodium nitrite, sodium tripolyphosphate, sugar, water and k-carrageenan. The brine was manually injected into the samples with a one needle syringe. The ingredients were added in different proportions, depending on the type of brine used (with k-carrageenan 0.25 and 0.5 kg/100 kg meat) and percentage of injected brine (20%, 30%, 40% and 50% in regard to the initial weight) so that in finished product the following quantities could be found: 1.8% salt, 0.3% sodium tripolyphosphate, 0.015% sodium nitrite, 0.3% sugar and 0.25% or 0.5% of k-carrageenan (Table 1). In order to determine the additive quantity in brine the following formula was used (www.fagro.edu.uy /~alimentos/ cursos/ prod_carnicos/ Unidad%204/ Chacinados%20 Salados.pdf):

$$\%\ additive\ in\ brine = \frac{\%\ additive\ wanted \cdot (100 + \%\ injection)}{\%\ injection} \qquad (1)$$

Table1. Brine recipes for different injection rates

Additive in product	Brine recipe for samples with 0.25 kg k-carrageenan/100kg meat				Brine recipe for samples with 0.5 kg k-carrageenan/100kg meat			
	Injection rate,%				Injection rate, %			
	20	30	40	50	20	30	40	50
Salt	10.79	7.798	6.2998	5.39	10.79	7.798	6.2998	5.39
Phosphate	1.79	1.299	1.0499	0.89	1.79	1.299	1.0499	0.89
Sugar	1.79	1.299	1.0499	0.89	1.79	1.299	1.0499	0.89
Nitrite	0.09	0.0649	0.05249	0.0449	0.09	0.0649	0.05249	0.0449
Water	84.01	88.453	90.7	91.96	81.31	87.37	89.79	91.25
k-carrageenan	1.499	1.083	0.8749	0.749	3.0	2.166	1.749	1.499

Tumbling and cooking yield

The brine absorption was calculated as the ratio of green meat weight to raw meat weight using the following equation (Pietrasik and Shand, 2004):

$$Tumbling\ yield\ (\%) = \frac{green\ weight}{raw\,weight} \cdot 100 \qquad (2)$$

The cooking yield was calculated in relation to the raw meat weight (Drummond & Sun, 2006) using the following equation:

$$Cooking\ \ yield\ \ (\%) = \frac{cooked\ \ weight}{raw\ \ weight} \cdot 100 \tag{3}$$

Expressible moisture (EM)

Green meat samples weighing 3.0±0.5g were placed in centrifuge tubes fitted with thimbles of filter paper and centrifuged at 604 g for 20 min at 4°C using a Refrigerated Centrifuge TGL-16M. Expressible moisture was calculated as the percentage of moisture lost during centrifugation as described by Pietrasik & Shand (2004).

$$\%\ \ EM = \frac{initial\ weight - final\ weight}{initial\ weight} \cdot 100 \tag{4}$$

Textural properties

The textural characteristics of samples were analyzed using a TA.XT*Plus* Texture Analyzer (Stable Micro Systems). The cooked samples were sheared perpendicular to the fiber direction with a shear attachment. Samples were cut in cuboids with side dimension of 2 cm. The technical parameters of the apparatus were: Compression Test Mode; Test Speed of 1,5 mm/s. Maximum force recorded during the test was reported as *firmness*, also known as the Warner-Bratzler shear force (Pietrasik, 2010); *toughness* as the area under the upper curve defined as material's ability to absorb the energy and to deform plastic without fracture (Larson, 2001); *fracturability* as the force when appears the first significant break in the curve representing the different particles` tendency for binding together (Maeda *et al*., 2002); *adhesiveness* as the maximum negative force and the *work of adhesion*, the negative area representing the work needed to overcome the attractive forces between the surfaces of the sample and the food.

Color measurement

Images of cooked samples (cross section) were taken by a digital camera with a proper lighting system according to the method described by Papadakis *et al*., (2000). The camera used had a resolution of 7 megapixels. Illumination was achieved with two Philips Natural Daylight fluorescent bulb lights with a color temperature of 6400 K, and a color index (Ra) close to 95%, according to Leon *et al*., (2006). The illuminating bulbs and the camera were placed in a wooden box whose interior walls were painted black to minimize background light. The angle between light source and camera lens was set to 45˚. The camera flash setup was off, without zoom. The focal distance was set to ~ 10 cm. The images were taken at a resolution of 3072×2304 pixels. After that pictures were processed using Microsoft Office software in JPEG format. Every picture was cut off from sides to center to eliminate any yellowish sides of the image, obtaining a final picture/image of 336×334 pixels, JPEG format, without compression. L*, a* and b* color parameters (CIE, 1976) were obtained using the Photoshop software (v6.0, Adobe Systems Inc., San Jose, CA). The coefficients were taken from Image/Histogram by previously setting in the lab color mode. L* is the luminance or lightness component, which ranges from 0 to 100, a* and b* are the two chromatic components, which range from -120 to +120 (a* from green (-a*) to red (+a*) and b* from blue (-b*) to yellow (+b*)). The software uses a scale, ranging from 0 to 255, to characterize lightness, as well as the values of a, and b (Lazaridou, *et al*., 2004). To convert these parameters to L*, a*, and b* the following formulas were used:

$$L^* = (L/250)\times 100 \qquad (5)$$

$$a^* = (a\times 240/255)-120 \qquad (6)$$

$$b^* = (b\times 240/255)-120 \qquad (7)$$

Additionally, hue angle (C°) was calculated as: $tan^{-1}(b^*/a^*)$, whereas chroma (D) was calculated as: $\sqrt{a^{*2} + b^{*2}}$ (Sawyer *et al*., 2008).

Statistical analysis

The statistical analysis, consisting on the Single factor ANOVA test (α = 0.05), was performed using Microsoft Office Excel 2007 software, from two replicates.

Results and discussion

Processing characteristics of Biceps femoris muscle

Tumbling yield

The data presented in Figure 1 demonstrate that increasing tumbling time up to 9 h and varying the brine rate injected into the samples significantly affected ($p<0.05$) samples' green weight.

Silva *et al*., (2011) also reported that the yield of beef *Biceps femoris* steaks immediately after tumbling was influenced by the tumbling time. Positive effects of increased tumbling times on brine absorption have also been observed in chicken fillets by Xiong & Kupski, (1999). However the weight gain of all samples after tumbling was roughly with 10% less than the injected one for all four injected rates, the weight loss being bigger for samples tumbled less.

When comparing values of tumbling yield for the two k-carrageenan rates used in this study, it was observed that for 20% and 30% injection rates values were significantly different ($p<0.05$) both for tumbling yield and for polysaccharide quantity used. When using 40% injection rate 0.5 % k-carrageenan did not lead to significant increases in tumbling yield ($p>0.05$). Increasing tumbling time up to 9 h in this case led to significant differences in tumbling yield. For 50% injection rate neither tumbling time, nor k-carrageenan quantity influenced tumbling yield ($p>0.05$). This leads to the idea that using little quantities of k-carrageenan can be effective when referring to tumbling yield only for injection rates that do not exceed 30%.

Cooking yield

Increasing tumbling time up to 9 h and growing the quantity of injected brine had a significant influence ($p<0.05$) on cooking yield values of *Biceps femoris* cuts

(Figure 2). Motycka & Bechtel (1983) also reported that pork *Semimembranosus* and *Biceps femoris* muscles presented an increased cooking yield after mechanical treatment by 2.1% and 3.6%, respectively. An important factor that increases the cooking yield of meat reported in earlier studies is a prolonged massaging / tumbling time that is believed to improve the salt migration into the meat. Tumbling times applied in different surveys varied from 30 min (Ockerman *et al.,* 1978) to 20 h (Gillett, *et al.,* 1981) of mechanical treatment and only after a minimum of 6 h of tumbling were reported increases in meat cooking yields (Krause *et al*., 1978; Theno *et al*., 1978).

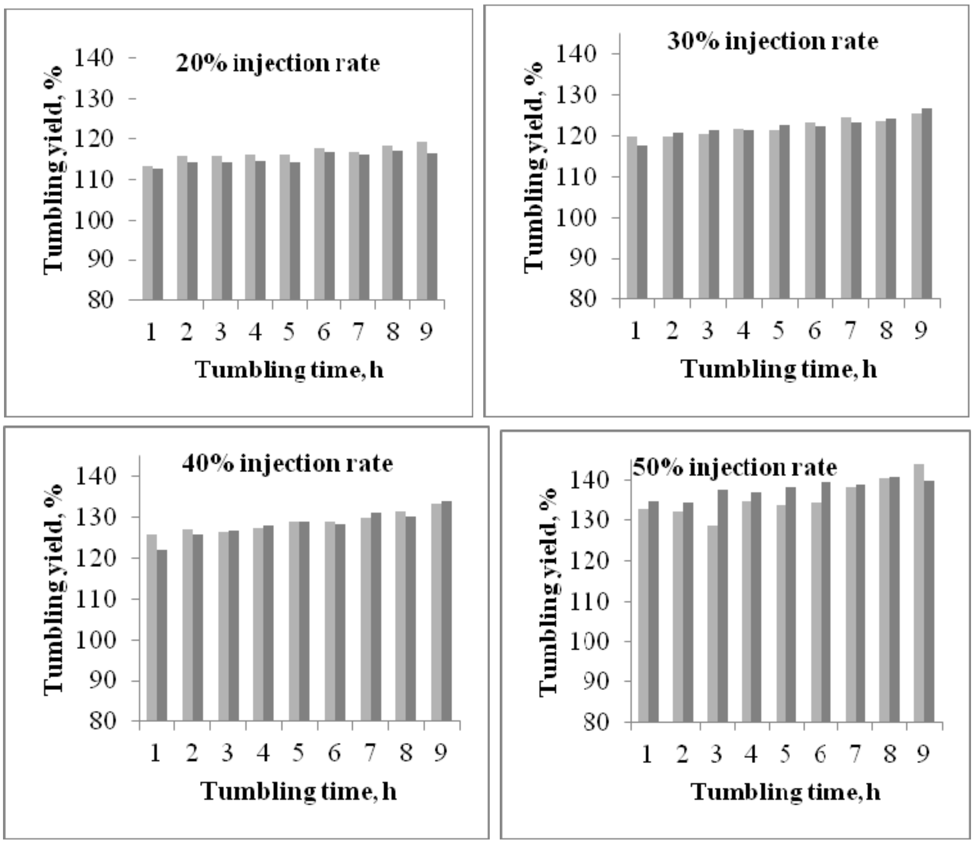

Figure 1. The influence of tumbling time, injection rate and k-carrageenan addition on the tumbling yield of Biceps femoris samples: 0.25% k-carrageenan; 0.5% k-carrageenan

Increases in the cooking yield values when using little proportions of k-carrageenan (0.25-0.55%) into brine were obtained by Ivanovic (2002). Walsh *et al*., (2010) also reported that for a better retention of brine level injected into the meat it should be supplemented with other additives to ensure a better water holding capacity.

Although cooking yield values increased after 9 h of tumbling for all four injected rates used regardless the type of brine injected into the meat, they did not exceed 120%. Particular case represented samples injected with 50% of brine containing 0.25% k-carrageenan. After six hours of tumbling, farther increasing tumbling time had no effect on cooking yield of the samples, values remaining around 115%. This leads to conclude that using little quantities of k-carrageenan (0.25 kg/100 kg meat) is insufficient when 50% of injection rate is desired.

Meat samples containing 0.5% k-carrageenan resulted in slightly higher values of cooking yield, compared to those with 0.25% k-carrageenan, in spite that the statistical differences were insignificant (p>0.05).

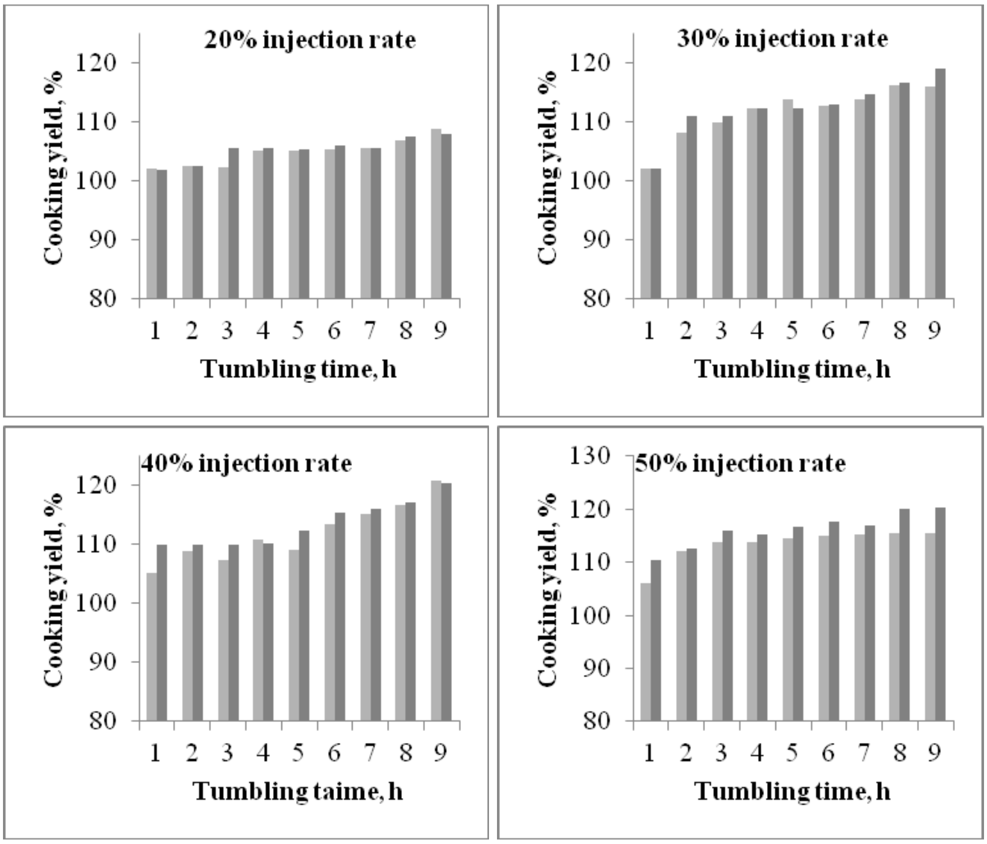

Figure 2. The influence of tumbling time, injection rate and k-carrageenan addition on the cooking yield of *Biceps femoris* samples: 0.25% k-carrageenan; 0.5% k-carrageenan

Expressible moisture

Water holding capacity of all samples was influenced both by injection rate and tumbling time. It was observed that increasing the amount of brine injected led to an increase of water expelled quantities during centrifugation of tumbled samples

($p<0.05$). A longer tumbling time had a benefic effect on water holding capacity of the samples. After 9 h of tumbling expressible moisture values visibly decreased ($p<0.05$), as seen in Table 2. This behavior was similar for both types of brine used in the study.

The effect of tumbling time on water holding capacity from this study resulted in accordance with previous published reports in which extended tumbling time has been described as a factor that improved the water binding characteristics of cooked meats (Dzudie, & Okubanjo, 1999; Pietrasik, 2004).

Table 2. The influence of tumbling time and injection rate on the expressible moisture of *Biceps femoris* samples containing 0.25% and 0.5% of k-carrageenan.

Tumbling time, h	EM%, 0.25% k-carrageenan				EM%, 0.5% k-carrageenan			
	Injection rate, %				Injection rate, %			
	20	30	40	50	20	30	40	50
1 h	19.46	25.50	21.63	23.60	22.40	18.05	24.45	23.01
2 h	14.99	25.36	22.36	18.23	16.45	21.86	18.33	20.90
3 h	13.34	19.54	15.01	20.21	14.17	17.21	15.83	18.02
4 h	13.08	21.52	14.77	18.83	13.26	15.74	14.39	18.76
5 h	12.37	12.13	15.31	18.45	13.01	16.29	13.53	16.81
6 h	12.86	12.97	14.68	16.19	13.88	14.12	13.53	16.85
7 h	12.00	12.04	10.17	13.46	11.41	15.19	13.16	14.74
8 h	11.16	12.29	9.68	9.36	10.76	11.67	12.98	17.38
9 h	10.42	11.10	10.14	10.96	11.51	11.38	11.30	13.60
P value	$p_{rows}<0.05$; $p_{columns}<0.05$;				$p_{rows}<0.05$; $p_{columns}<0.05$;			

The decreased values in the expressible moisture can be attributed to the lateral expansion of the myofibrils together with the protein solubility. According to Xiong *et al.,* (2000) study, an increase of salted meat hydration and binding capacities leads to an extension of the filaments network so that a larger amount of water could be retained. Akse *et al*., (1993) reported that "salting-in" effect of the muscle occurs at lower salt concentrations (50 g/L) and "salting-off" effect is observed at larger salt concentrations (90-100 g/L), which also implies a stronger water-salt connection so that the proteins are dehydrated afterwards.

Results showed that the matrix formed in the muscular network of B*iceps femoris* samples after a longer tumbling time had a better water holding capacity in regard to injection rate. For samples injected with 50% brine for both types of brine used, expressible moisture values for most of the samples were higher which explains lower cooking yield values. Basically a higher quantity of liquid resulted in a "dilution" of myofibrillar proteins solubilized due to the effect of salt on myofilaments so that the meat-brine matrix could not be formed inside muscle.

Textural properties

Increasing tumbling time up to 9 h as well as the level of injected brine resulted in decrease of firmness for all samples ($p<0.05$) for both brine types used. Cooked *Biceps femoris* cuts tumbled for 9 h needed less shearing force compared to samples tumbled for one hour (Table 3). Also, increasing the quantity of injected brine led to a decrease in firmness values for both types of brine (by 0.25% and by 0.5% k-carrageenan).

More k-carrageenan addition (0.5% versus 0.25%) decreased the firmness of *Biceps femoris* samples, less force being necessary for cutting the meat.

At low injection rates (20% and 30%), after one hour of tumbling, muscle samples containing 0.25% k-carrageenan showed grater values for firmness, compared to samples injected with the same quantity of brine containing more k-carrageenan (0.5 kg/100 kg meat). It is worth mentioning that a greater quantity of k-carrageenan provides tenderer meats in a shorter tumbling time.

Increasing tumbling time up to 9 h, significantly lowered ($p<0.05$) firmness and toughness values for samples injected with brine containing k-carrageenan (0.25% and 0.5 kg/100 kg meat), but did not affect adhesiveness and work of adhesion of the samples. However increasing tumbling time up to 9 h determined a drop of the particles` bonding tendencies, so that muscular fibers could keep the ability of staying united regardless the amount of brine injected. Results showed that a prolonged mechanical treatment lowered the forces of attraction between particles.

Similar to samples containing 0.25% k-carrageenan, those with 0.5% k-carrageenan presented significantly different values ($p<0.05$) regarding the firmness and toughness. Adhesiveness and work of adhesion did not show to be influenced by the degree of injection and by the quantity of added polysaccharide. As in the case of samples with 0.25% k-carrageenan, the dropping of these parameters was also determined by the time of mechanical treatment.

Fracturability values were close to those of firmness in the entire study, but for some samples it could not be measured. That is because meat does not have the property of being actually crumbly. Fracturability is included as a secondary parameter together with chewiness and gumminess in cohesiveness (Ahamed, 2007), defined as the intermolecular attraction by which the elements of a body are held together. Sparado & Keeton (1996) stated that poor cohesiveness means poor binding characteristics of the particles.

Color

Table 4 displays the obtained instrumental color parameters such as: lightness (L*), redness (a*) and yellowness (b*), as well as the calculated Hue angle (C˚) and Chroma (D) for pork B*iceps femoris* samples injected under different experimental conditions.

Table 3. The influence of tumbling time and injection rate on the textural characteristics of cooked *Biceps femoris* samples containing 0.25% and 0.5% of k-carrageenan

Sample	Tumbling time, h	Firmness, kg force				Toughness, kg force×s				Adhesiveness, kg force ($\times10^{-2}$)				Work of adhesion, kg force×s ($\times10^{-2}$)				Fracturability, kg force			
		Injection rate, %				Injection rate, %				Injection rate, %				Injection rate, %				Injection rate, %			
		20	30	40	50	20	30	40	50	20	30	40	50	20	30	40	50	20	30	40	50
0.25 % k-carrageenan	1	8.63	8.24	5.16	5.86	82.51	71.8	63.4	49.5	45	100	38	15	18	71	22	06	7.01	8.55	6.18	3.54
	2	7.10	7.30	4.98	5.23	75.51	72.2	72.7	51.9	56	75	58	44	29	63	13	18	5.54	7.72	6.37	NI
	3	8.06	6.87	4.49	4.67	83.15	80.6	73.7	53.3	37	115	41	28	12	88	27	08	5.31	7.73	7.52	3.84
	4	7.49	6.28	4.53	4.53	76.80	89.5	67.9	46	51	66	32	09	17	42	15	01	3.06	6.63	4.42	NI
	5	6.70	5.37	4.12	3.96	70.58	66.9	53.1	51.4	28	80	67	37	10	68	35	12	3.64	6.88	3.90	3.90
	6	6.24	4.52	3.88	3.56	70.94	79.6	60.2	41	19	100	10	27	09	32	03	08	NI	8.46	2.80	NI
	7	5.87	4.68	3.91	3.25	63.61	76.6	53	44.6	34	113	52	42	17	67	23	20	1.96	7.59	4.38	3.35
	8	5.51	4.26	3.61	3.43	60.33	61.6	51	40.9	23	35	27	10	09	34	14	01	NI	7.13	3.89	2.76
	9	5.83	4.79	3.36	3.35	63.40	70.9	57	29.2	34	60	33	23	12	30	14	08	NI	7.16	5.83	1.75
	P value	$P_{rows} < 0.05$; $p_{columns} < 0.05$				$P_{rows} < 0.05$; $p_{columns} < 0.05$				$P_{rows} > 0.05$; $p_{columns} < 0.05$				$P_{rows} > 0.05$; $p_{columns} > 0.05$				-			
0.5 % k-carrageenan	1	6.15	7.66	6.75	6.08	59.4	78.18	48.62	53.82	86	78	24	25	35	33	10	9	6.03	6.55	4.29	5.22
	2	5.51	7.88	6.32	5.49	51.0	73.63	48.90	52.48	35	20	33	43	11	09	11	17	NI	5.74	4.06	4.66
	3	4.98	7.31	5.75	4.72	51.2	65.02	47.40	50.84	38	65	35	24	11	39	14	10	NI	6.06	3.09	3.25
	4	5.13	5.09	5.48	4.80	44.2	66.41	49.88	42.52	53	57	40	13	17	28	19	4	6.38	5.44	4.23	3.76
	5	4.44	4.56	4.76	3.99	47.1	52.73	41.02	38.10	45	17	37	05	14	07	14	2	5.86	5.50	2.43	3.39
	6	4.35	4.58	4.13	3.39	45.3	47.53	43.15	40.43	40	20	13	20	43	08	5	8	5.08	2.66	3.06	2.20
	7	3.56	3.68	3.50	3.33	38.5	49.96	39.04	35.72	29	23	26	16	13	06	8	5	2.59	3.12	NI	2.49
	8	3.73	3.59	3.71	3.25	42.9	42.07	35.73	36.68	43	23	18	23	07	09	7	9	4.39	3.41	3.49	2.77
	9	3.40	3.30	3.24	3.37	37.9	50.27	33.42	34.74	23	29	27	21	07	11	12	7	4.37	4.14	2.63	2.24
	P value	$P_{rows} < 0.05$; $p_{columns} < 0.05$				$P_{rows} < 0.05$; $p_{columns} < 0.05$				$P_{rows} > 0.05$; $p_{columns} < 0.05$				$P_{rows} > 0.05$; $p_{columns} < 0.05$				$P_{rows} < 0.05$; $p_{columns} < 0.05$			

For every type of brine used, after reading CIELAB parameters resulted that neither tumbling time, nor quantity of brine injected into the sample determined significant changes in color ($p>0.05$) of the processed meat (data not shown). Baublits *et al*., (2005), reported no differences in color components for two pump rates (12 and 18%) used in the survey, color components being sensible only to phosphate concentrations, greater quantities of it (0.4%) improving meat appearance. Neither consumers have detected differences in color for pork loin muscle injected with 0%, 6%, and 12% brine (Baublis, 2006). Hayes *et al*., (2007) declared that vacuum-tumbling had no positive or negative effects on color of dry cured beef. No significant differences between tumbling times (5 min and 25 min) in color were found by Moon *et al*., (2007).

Table 4. The influence of tumbling time and injection rate on color characteristics of pork *Biceps femoris* samples containing 0.25% and 0.5% of k-carrageenan

Brine type	L*	a*	b*	Hue angle	Chroma
0.25% k-carrageenan	52.29	9.82	6.98	0.633	12.14
0.5% k-carrageenan	51.80	9.95	6.45	0.583	11.94
p_{value}	$p< 0.05$	$p>0.05$	$p>0.05$	$p<0.05$	$p>0.05$

When comparing the brine types used between them, there were recorded significant changes ($p<0.05$) regarding some color components. Hence the values have been centralized, and a single average of all data for each type of brine used, was displayed in order to evaluate the chromatic changes obtained after k-carrageenan addition in different proportions (Table 4).

More k-carrageenan addition (0.5% versus 0.25%) determined a significant drop in meat lightness ($p<0.05$). L* values decreased with increasing the polysaccharide proportion, from 52.29 at 0.25% k-carrageenan to 51.8 at 0.5% k-carrageenan, respectively. However L* values were above 50, resulting that meat was more bright than dark. Hong, *et al.,* (2008), reported that the addition of k-carrageenan (0.25%, 0.5%, and 0.75%) had no effect on the L*-value of the restructured pork treated under pressure.

Regarding a* and b*color components, values were in the red-yellow quadrant (+a*; +b*) and there was found an inverse proportionality between them. When a* component values decreased, b* component ones increased. K-carrageenan addition, in both concentrations, did not interfere in the chromatic distribution of samples color.

Similar to a*and b* color components, chroma (D) and hue angle (C°) values varied slightly after 0.5% of k-carrageenan addition. Hue angle departed little from red tone (0°) if considering color distribution, toward orange (30°), being yet very far from it.

Conclusions

Water holding capacity of *Biceps femoris* samples after tumbling process was positively influenced both by injection rate and tumbling time. Increasing tumbling time up to 9 h and growing the brine percent injected into the muscles positively influenced the weight gain of pork B*iceps femoris* samples after tumbling and cooking process. Adding 0.5% of k-carrageenan into the meat-brine system did not lead to further increase of tumbling or cooking yield in relation to samples with less polysacharide in the system.

Muscular fiber network kept its structure regardless of brine quantity used for injection, but a prolonged tumbling time caused partial structure disintegration by decreasing the attraction and adhesion forces. An increase in k-carrageenan addition determined a decrease of samples firmness, less force being necessary for muscle shearing.

Pork *Biceps femoris* color components were not affected by the injection rates or the tumbling time, regardless of the type of brine used for injection. However, more k-carrageenan addition led to a decrease of samples' lightness and color saturation (Chroma), without affecting the other color components.

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