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EFFECT OF TUMBLING TIME AND INJECTION RATE ON THE PROCESSING CHARACTERISTICS, TENDERNESS AND COLOR OF PORK *BICEPS FEMORIS* MUSCLE

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The effect of tumbling time (0-9 hours) on quality characteristics of cooked pork meat processed with 30% and 40% injection level was investigated. The properties of injected and tumbled meat were determined by measuring processing characteristics (tumbling yield, cooked yield, expressed moisture), color and textural characteristics (shear force, texture profile analysis). The increase of the tumbling time up to 9 hours favorably affected hydration properties and increased the cooked yield. It also decreased the shear force and hardness of the samples. None of the techniques utilized did affect the chromatic components ($p>0.05$) of the samples, however there were differences between samples regarding the injection rate.

Keywords: injection, tumbling, firmness, expressed moisture

Introduction

Curing is a preservation method used since ancient times and helps improving the technological and sensory characteristics of meat (Siro *et al*., 2009). It is used to improve the flavor and to increase juiciness, and it contributes to improving tenderness and to increasing the water holding capacity of meat products (Weiss, 1973).

The main ingredients that must be used to cure meat are salt, nitrite and phosphates. Salt acts as a preserving agent and is also responsible for causing the physico-chemical and biochemical phenomena that contribute to the development of flavor (Shackelford *et al*., 1989; Gill *et al*., 1999; Vestergaard *et al*., 2005).

Furthermore, it improves the water retention properties of the meat as a consequence of an increase in the solubility of myofibrillar proteins (Hongsprabhas and Barbut, 1999; Lawrence *et al*., 2003). Nitrite comes mainly for product color, but it also increases the flavor and acts like a bacteriostatic agent. Phosphates are added to the cure or brine to increase the water-binding capacity and thereby increase the yield of the finished product. However, other substances can be added to modify flavor, or to reduce muscle shrinkage during processing (Frederick, K. Ray, Oklahoma University).

Nowadays , 63-80% of the meat produced in the world is processed to some extent (Andersen, 2000) and there is a variety of processed meat products. When considering the pork muscles, cured-cooked processes dominate. To accelerate the diffusion of the brine into the meat and to get a more uniform salt distribution in the meat, the processing often involves tumbling or massaging (Ghavimi *et al.*, 1986; Katsaras, 1993, Hullgerg *et al*., 2005). Tumbling induces tissue structure softening and rupture, which causes an increase of brine sorption and protein extraction, and consequently an increment of cooking yield (Xargayo *et al*., 1998).

Considering the processing time or weight ratio of the brine to the meat required to obtain a product with better characteristics from a sensorial or a technological point of view, neither scientists nor manufacturers came to a similar standpoint. In two similar studies, Lowlis *et al*. (1992) and Hullberg *et al*. (2005) reported an increased tenderness as hams were tumbled for 3 or 6 hours, whereas Bedinghaus *et al*., (1992), after an intermittent tumbling time of 18 hours, found no significant effect on sensorial tenderness. Pietrasik *et al*. (2004) have extended tumbling time up to 16 hours and reported an increase in cooking yield.

The aim of the present study was to evaluate the effect of tumbling time and brine rate on some characteristics of pork muscle.

Materials and methods

The pork *Biceps femoris* muscle sampled two days after slaughter was used for the present study. All visible fat and connective tissue was removed. The average pH of the meat was 6.21±0.07. The non-meat ingredients used to prepare the brine were sodium chloride, sodium nitrite and sodium tripolyphosphate.

All samples were manually injected to 130% and 140% over the raw weight with brine formatted to give 1.8% salt, 0.3% sodium phosphate (Pietrasik and Shand, 2004; 2005) and 0.015% sodium nitrite.

After injection the meat was vacuum tumbled (Reveo Marivac, USA) under a constant vacuum of 85 MPa, for 1 to 9 hours in an interval of 20 minutes of work and 10 minutes of resting periods. The rotational speed of the barrel was 14 rpm, what makes a total of 5040 rotations in the case of the 9 hour tumbling. The process was carried out in a chilled room at 4 - 5°C.

The pieces of meat were weighed before injecting (further named raw weight or raw meat by the case) and after tumbling (farther named green weight, respectively green meat) in order to determine the brine retention. After tumbling, meat samples (sealed in glass test tubes with suitable volumes for collecting the liquid released during cooking) were water cooked in a water bath (Memmert, WNB-45, Germany), gradually increasing the water temperature with ~1.5°C/ min from 20±2°C to 75°C to a final internal temperature of 72°C measured with a thermocouple. After cooking the samples were cooled in running water and weight.

Yield

The brine absorption was calculated as the ratio of green meat weight to raw meat weight using the following equation:

$$Tumbled\ \ yield(\%) = \frac{green\ weight}{raw\ weight} \times 100 \tag{1}$$

The cooked yield was calculated in relation to the raw meat weight (before injection) (Drummond and Da-Wen Sun, 2006) using the following equation:

$$Cooked\ Yield(\%) = \frac{cooked\ weight}{raw\ weight} \times 100 \tag{2}$$

Expressed moisture (EM)

Samples of green meat of known weight (3.0±0.5g) were placed in centrifuge tubes fitted with thimbles of filter paper and centrifuged (Refrigerated Centrifuge TGL-16M) at 2400 rot/minute for 20 minutes at 15°C. EM was calculated as the percentage of moisture lost during centrifugation (Pietrasik and Shand, 2004).

pH measurements

Duplicate samples of minced meat from each cut were homogenized with distilled water and the pH was measured using a Methrom pH meter (Switzerland).

Soluble proteins

After cooking, the soluble proteins from the liquid expelled were determined using the Lowry method (Lowry *et al*., 1951). In this method, proteins are first treated with alkaline copper sulfate in the presence of tartrate, followed by the addition of Folin – phenol reagent. The –CO–NH– (peptide bond) in polypeptide chain reacts with copper sulfate in an alkaline medium to give a blue-colored complex. In addition, tyrosine and tryptophan residues of protein cause a reduction of the phosphomolybdate and phosphotungstate components of Folin–Ciocaulteu reagent to give a bluish product that contributes toward enhancing the sensitivity of this method. The quantity of proteins (mg/l) from the solution obtained was determined using a T80+UV/VIS Spectrometer (PG Instruments Ltd) at a wavelength of 726 nm and the soluble protein was expressed as BSA.

Textural properties

The textural characteristics of samples were analyzed using a TA.XT. Plus Texture Analyser. The samples were sheared perpendicular to the fiber direction with a Warner-Bratzler shear attachment. The work parameters of the apparatus were: Compression Test Mode; Test Speed of 1.5 mm/s. Samples were cut in cuboids with side dimension of 2 cm. The test was performed after 5 days of storage in aluminum foil at +4°C.

In Figure 1. are shown all the investigated parameters. Maximum force recorded during the test was reported as *firmness* or hardness (kg Force); the *fracturability* as the force when appears the first significant break in the curve (named also brittleness), sometimes it does not appear, the curve is very smooth and the first significant break in the curve is the maximum force recorded during the test; *toughness* as the area under the curve; *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 probe and the food.

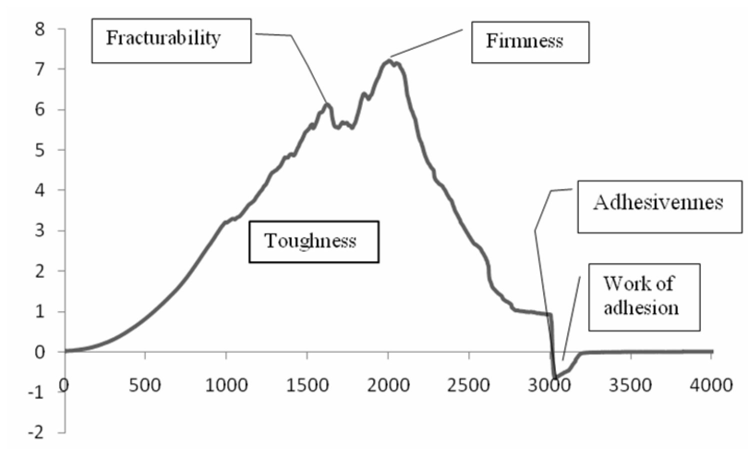

Figure 1. The parameters determined in the textural analysis test

Color

Images of samples were taken by the digital camera with a proper lighting system as described by Papadakis, Abdul-Malek, Kamdem, and Yam (2000). 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, and a* and b* are the two chromatic components, which range from -120 to +120 (a* from green to red and b* from blue to yellow) (Adobe Photoshop 5.0 User Guide for Mackintosh and Windows, 1998). 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:

$$L^* = (L/250) - 100 \quad (3)$$

$$a^* = (a \times 240 / 255) - 120 \quad (4)$$

$$b^* = (a \times 240 / 255) - 120 \quad (5)$$

Additionally, hue angle (C°) was calculated as: $(tan(b^*/a^*))^{-1}$, 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) considering the value of the Fisher statistic test (F), was performed using Microsoft Office Excel 2007 software.

Results and discussion

Processing characteristics

The increase of the tumbling time up to 9 hours (5040 rotations) significantly improved the cooking yield (p<0.05) in case of 40% injection over the raw weight and had little effect when injecting 30% over the raw weight (Tables 1 and 2). But it can be observed that the yields from 8 and 9th hours were similar for both of the injecting percentages. It means that samples injected with 40% of brine lost more water in the cooking process although they gained more brine in the tumbling process. It leads to the hypothesis that in order to retain the entire amount of brine other ingredients are needed (Walsh *et al*., 2010).

Table 1. Effect of tumbling time on the processing characteristics of cooked pork *Biceps femoris* muscle injected to 130% over raw weight

Sample	Tumbled yield, %	Cooked yield, %	EM, %	*p*H	Soluble protein, mg/l
Tumbling time, h					
1	124.13	90.32	20.65	5.99	0.065
2	119.49	95.68	17.80	5.98	0.079
3	126.17	99.89	18.25	5.95	0.076
4	123.13	104.32	11.00	5.99	0.074
5	120.62	104.63	13.85	6.00	0.073
6	122.32	105.37	14.60	6.05	0.069
7	117.74	107.75	16.45	5.99	0.091
8	125.69	119.34	17.25	5.98	0.101
9	123.63	121.74	11.50	5.99	0.116
P value	*0.7955**	*0.7387**	*0.0001 ***	*0.8492**	*0.00137***

**F<F crit, **F>F crit*

Table 2. Effect of tumbling time on the processing characteristics of cooked pork *Biceps femoris* muscle injected to 140% over raw weight

Sample	Tumbled yield, %	Cooked yield, %	EM, %	*p*H	Soluble protein, mg/l
Tumbling time, h					
1	131.54	97.95	20.3	6.23	0.074
2	133.03	98.26	22.2	6.16	0.099
3	129.05	102.33	17.4	6.06	0.092
4	138.92	105.82	19.7	5.89	0.104
5	134.17	107.07	21.9	5.85	0.105
6	134.44	109.25	18.5	5.96	0.105
7	132.65	115.86	10.5	5.88	0.106
8	128.55	119.90	15.6	5.87	0.106
9	136.01	120.72	15	6.00	0.111
P value	*0.0680**	*0.003***	*0.0003***	*0.0299***	*0.0032***

**F<F crit, **F>F crit*

The capacity of brine holding after tumbling, expressed by EM, increased with the tumbling time ($p<0.05$).

The soluble proteins from the liquid released during cooking increased in the case of 8-9 hours of tumbling and it had smaller values in the case of 130% brine injection. This is an undesired phenomenon, because it causes an important loss of muscle proteins. The cooking test indicated that, when tumbled less, the meat released sarcoplasmatic proteins under the form of a heat induced protein aggregate to the lateral parts of the meat in the first 6 hours of the tumbling. This moment corresponds to the forming of binding material, in the drum, from the released sarcoplasmatic and myofibrillar proteins, when the rolled pieces of meat were well bound together.

Textural and color characteristics

The tumbling regime had an important effect on textural parameters of the meat injected to 140% above original weight compared to the case in which the samples were processed to 130% injection level (Table 3). Unlike the samples that were injected to 130% over original weight that had no significant differences between values ($p>0.05$) for firmness, those injected to 140% presented lower values for firmness beginning with the 4th hour of tumbling.

Table 3. Effect of tumbling time on textural characteristics of cooked pork muscle Biceps femoris muscle

Tumbling time, hours	Firmness, kg Force	Toughness, kg Force ×s	Adhesiveness, kg	Work of adhesion, kg×s	Fracturability, kg Force
130% injection over raw weight					
1	13.069	71.877	-1.004	-0.713	10.547
2	10.705	72.218	-0.753	-0.630	nd
3	11.960	80.602	-1.151	-0.881	10.727
4	11.643	89.564	-0.667	-0.423	10.810
5	10.878	66.949	-0.809	-0.685	nd
6	11.242	79.688	-1.007	-0.327	8.461
7	11.222	76.686	-1.536	-0.679	9.592
8	9.688	61.629	-0.351	-0.341	7.128
9	10.151	70.933	-0.600	-0.308	7.756
P value	*0.1019**	*0.2312**	*0.1271**	*0.4257**	*0.0838**
140% injection over raw weight					
1	11.566	111.178	-0.384	-0.221	7.678
2	11.368	105.526	-0.589	-0.130	nd
3	10.543	63.4693	-0.411	-0.273	nd
4	10.264	67.9369	-0.327	-0.156	4.421
5	8.391	53.1301	-0.676	-0.357	3.900
6	9.313	60.2889	-0.103	-0.033	2.805
7	7.485	53.0936	-0.529	-0.233	4.380
8	6.250	51.1419	-0.272	-0.147	3.891
9	7.113	57.9098	-0.337	-0.142	7.076

**F<F crit, **F>F crit, nd - not determined*

The toughness was higher in the case of 130% brine injection while the adhesiveness was smaller for samples injected to 140% over green weight. This behavior can be explained by the fact that with more added brine the protein-water interactions and gel formation in myofibrils and connective tissue proteins is better. Mechanical conditioning has also been found to increase tenderness of cured meat. This is due to the disruption of cellular connective tissue and increased moisture retention upon cooking. This tenderizing effect can be applied to heavier primal cuts to produce a more desirable product.

Table 4. Effect of tumbling time on color characteristics of cooked pork muscle *Biceps femoris* muscle

Tumbling time, hours	**L***	**a***	**b***	**Hue angle, C°**	**Chroma, D**
		130% injection over raw weight			
1	47.85	10.16	6.93	1.5878	14.1440
2	54.31	10	8.75	0.8514	13.3707
3	50.27	10	10.73	0.8649	16.4813
4	51.02	11.76	10.56	0.6046	17.5307
5	49.69	10.82	10.01	0.5206	16.2929
6	48.5	12.17	9.76	1.0928	16.3923
7	54.43	11.76	8.56	1.6686	13.8078
8	52.95	11.76	8.09	1.7120	13.0307
9	59.42	9.88	7.99	0.2647	10.0463
P value	*0.952**	*0.972**	*0.931**	*0.846**	*0.757**
		140% injection over raw weight			
1	54.89	8,66	7.05	1.5350	14.1242
2	59.03	9.42	6.11	1.3192	11.4393
3	60.78	9.48	5.17	1.6482	10.8463
4	62.6	9.73	5.2	0.7814	10.4586
5	60.26	9.58	5.17	1.6695	10.9387
6	58.6	9.95	6.11	1.4185	11.8904
7	62.44	10.92	6.11	1.5967	12.4406
8	64.2	10.44	5.17	2.0600	12.5294
9	71.84	10.76	4.23	2.6592	12.6719
P value	*0.994**	*0.986**	*0.951**	*0.964**	*0.330**

**F<F crit*

Considering the color of the analyzed samples, the results showed that the tumbling time did not affect any of the chromatic components of the samples. That is because sodium nitrite helped stabilizing the meat color regardless the technological processes used. However, values of the chromatic components were different for 130% injection and 140% of brine injection. Meat injected with less brine was darker, as show the L*. The parameters a* and b* were smaller in case of

140% injection because the quantity of added sodium nitrite was calculated in relation to meat and not to the entire system and therefore, with higher quantities of added brine the redness and yellowness values were lower.

The same tendency as L*, a* and b* parameters had chroma values. With more added brine the chroma values decreased, meaning that the meat was more shaded. Samples injected at a lower rate had greater chroma values and were more vivid.

Myoglobin concentration (Froning *et al*., 1968) and the formation of a reduced nicotinamide-denatured globin hemochrome during cooking (Cornforth *et al*., 1986) are just two factors related to the change of color from red to pink in cooked meat products; yet, it is the fact that a high ultimate muscle pH can inhibit the formation of a brown cooked meat color (Schmidt and Trout, 1984). Mendenhall (1989) and Trout (1989) indicated that when the fresh meat pH exceeded 6.0 in cooked meat the red color persisted. Our experiments allowed gathering similar observations in case of using fresh meat having pH of 6.21±0.07 so that a* values exceeded those of b*.

Conclusions

Tenderness and colour of meat products are two of the most important quality attributes affecting consumer satisfaction. Our results showed that both characteristics are affected by tumbling time and brine:meat ratio. Our observations are in agreement with previous studies showing that meat tumbled for a longer time is usually more tender than the non-tumbled or tumbled for less time meat.

Considering the processing characteristics, the results showed bigger cooked yield for meat injected with 40% brine and better textural properties although color differences were not significant. We conclude that for a better equilibrium between meat and brine we need more than 30% of it.

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