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# EFFECTS OF MASSAGING TIME AND DRUM SPEED ON TEXTURE AND STRUCTURE OF TWO BEEF MUSCLES

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## ABSTRACT

Investigations have been done on selected beef muscles: *m. biceps femoris* and *m. semimembranosus* including their injecting with curing brine and massaging. It was found that BF is characterized by fibres of a larger mean cross-sectional area as well as a thicker peri- and endomysium and it is also harder and more difficult to chew than SM. Massaging resulted in an increase of mean fibre cross-sectional area, peri- and endomysium changes and in a reduction of hardness and chewiness, however the drum speed and time-dependent changes differed between the muscles. To achieve a significant reduction of hardness and chewiness BF required longer massaging time, compared to SM. At the massaging regime applied in this study, to arrive at comparable textural parameters in the two muscles, BF should be effective massaged for 12 h at 20 rpm drum speed and SM – 8 h at 5 rpm drum speed or 4 h at 20 rpm drum speed.

**Key words:** beef muscles, massaging process, texture, structure

## INTRODUCTION

It is widely known that massaging, due to mechanical effects on brine-injected meat, induces physical and histological changes about different intensities in it, in dependences from massaging conditions [1, 2, 6, 14, 27, 30, 31. As a result of loosening of and damaging meat structure, massaging causes an increase in brine sorption and protein extraction into intercellular spaces and to the outside, myofibrils and muscle fibres swelling at the same time [13, 19, 28, 33]. The consequences include, i. a., an increase in meat tenderness and cohesiveness, WHC and yield [4, 17, 29, 34]. Numerous workers found the muscles of slaughtered animals, especially beef muscles, to differ both in texture and in structure [2, 7, 11, 20, 25]. The muscles were also shown to differ in their susceptibility to tenderisation [3, 23, 25]. It can be thus assumed that different beef muscles will require different massaging parameters.

The present work was aimed at following effects of massaging time and drum speed on texture and structure of topside (*m. semimembranosus*) and top round (*m. biceps femoris*) of cattle.

## MATERIALS AND METHODS

The study involved selected beef ham muscles: *m. biceps femoris* (BF) and *m. semimebranosus* (SM) dissected out of the quarter-carcasses of bulls slaughtered at 30 months old. The muscles were selected, and then dissected, from quarter-carcasses, stored at the cold room at 4°C for 24 h, at the Mas-AR Food Industry and Experimental Production Plant, Agricultural University of Szczecin. A total of 50 kg each muscles were selected to this study. Each muscles were cut to about 900 g weight; were injected with curing brine containing 7.8 kg NaCl, 0.9 kg polyphosphate, 0.2 kg sodium ascorbate, and 91.1 kg water per 100 kg of brine, until a 30% weight increase was obtained.

The muscles cuts were massaged in a MP-74 PEK-MONT s.c.® vacuum massaging apparatus under following massaging conditions:

- 5 and 20 rpm drum speed,
- 30 min massaging, 30 min pause
- the drum was filled to about 70% of its capacity
- massaging temp. 4°C
- vacuum: -0.8 bar

Five samples from each type of muscle were collected for assays after 0, 2, 4, 6, 8 and 12 h of effective massaging. Simultaneously with meat sample collection, about 35 ml exudate portions were collected with spatula into beakers, from the muscles surface, and muscle samples about 0.5 $cm^3$ were cut out for structure parameter measurements. The brine injection muscles were control (non-massaged) samples. To counteract a substantial reduction of the total ham weight in the drum because of sampling, the drum contents were supplemented each time with specially marked individual muscles, added in the amount equal to that which had been removed.

Each time samples were collected from both the massaged and control meat; muscles were sealed in a heat-resistance bag, and subjected to cooking in water heated to 75±1°C, until the temperature inside the sample reached 68±1°C. The temperature was measured with a MT-2 thermometer. Subsequently, the samples were cooled down, reweighed and stored at 4±1°C for abuot 24 h until the assays were made. The 20±1 mm thick slabs were cut off, across the fibres, from each group of muscles by electric knife.

### Texture measurement

Muscle textural characteristic were assayed following the Texture Profile Analysis (TPA double penetration test) procedure [5], with a computer-interfaced Instron 1140. The test involved driving a 0.96 cm diameter shaft twice into a 20±1 mm high sample, parallel the fibres, down to 80% of its height (16 mm); 50 mm $min^{-1}$ crosshead rate being applied. The force-deformation curve obtained served to calculate meat hardness, cohesiveness, and chewiness. The procedure was repeated 10 times on each sample batch.

**Structural analyses**

Three samples of raw muscles, both massaged and non-massaged (control) measuring 5 mm x 5 mm x 5 mm were fixed in the Sannomiya solution [6] for 12 h, passed through the alcohol series, and embedded in paraffin. The paraffin blocks were cut transversely into 7-8 µm slices. Each slice was stained in hematoxylin and eosin. Each muscle produced 4-5 microscope mounts.

Fibre cross-sectional area, fibre diameter as well as perimysium and endomysium thickness in each mount were determined, using an image analysis programme (Computers Scanning System, Poland), from several bundles containing altogether 300-400 fibres. The vertical and horizontal diameters of muscle fibres were also measured. The shape of the muscle fibre was determined by the ratio diameters H and V. If the rate of diameters H and V is nearer 1, the shape of fibres was more regular.

**Exude viscosity and thermal drip measurements**

Viscosity of exudates collected from the surface of massaged meat was determined with an RV2 Rheotest 2 rotating viscometr. After placing 30 ml exudate samples maintaining 4±1°C in measuring cylinder $S_2$, viscosity was measured at the shear rate of 145.8 cm $s^{-1}$. Viscosity was measured twice on each sample.

Coking loss (the percentage of weight loss) was determined by weighting individual muscles before and after cooking.

**Statistical treatment**

All the calculations were performed with Statistica v.6.0 PL software. A mean and standard deviation was calculated for each samples. A significance of differences was explored by applying Student's *t* test at P = 0.05.

## RESULTS AND DISCUSSION

Comparison of two non-massaging muscles texture parameters showed the BF muscle to have by about 25% higher hardness and 35% higher chewiness than SM muscle; the latter muscle was characterised by the highest cohesiveness (Table 1 and 2). Other workers, i.a., Dransfield [7], Mc Keith et al. [16], Oryl [20], Shackelford et al. [25], too, demonstrated the BF muscle to be harder than SM.

**Table 1. Effects of massaging time and drum speed on texture changes of BF muscle**
**a, numbers in columns, marked with identical superscripts are not significantly different within time massaging (P≥ 0.05)**
**1, numbers in columns, marked with identical subscripts are not significantly different among drum speed (P≥ 0.05)**

| Effective massaging time [h] | Hardness [N] | | Chewiness [N·cm] | | Cohesiveness [-] | |
|---|---|---|---|---|---|---|
| | 5 rpm | 20 rpm | 5 rpm | 20 rpm | 5 rpm | 20 rpm |
| 0 | $108.6^{a}_{1}$ ±11.50 | $108.6^{a}_{1}$ ±11.50 | $78.9^{a}_{1}$ ±12.20 | $78.9^{a}_{1}$ ±12.20 | $0.488^{a}_{1}$ ±0.043 | $0.488^{a}_{1}$ ±0.043 |
| 2 | $106.2^{a}_{1}$ ±9.60 | $100.6^{ab}_{1}$ ±12.40 | $76.5^{ab}_{1}$ ±14.20 | $73.9^{a}_{1}$ ±10.70 | $0.490^{a}_{1}$ ±0.075 | $0.475^{a}_{1}$ ±0.062 |
| 4 | $103.6^{ab}_{1}$ ±11.30 | $96.5^{a}_{1}$ ±11.80 | $73.4^{ab}_{1}$ ±13.80 | $68.7^{ab}_{1}$ ±10.50 | $0.492^{a}_{1}$ ±0.065 | $0.490^{a}_{1}$ ±0.083 |
| 6 | $100.4^{ab}_{1}$ ±9.20 | $91.9^{a}_{1}$ ±7.40 | $70.3^{ab}_{1}$ ±9.40 | $63.3^{ab}_{1}$ ±6.70 | $0.485^{a}_{1}$ ±0.089 | $0.495^{a}_{1}$ ±0.068 |
| 8 | $96.9^{ab}_{1}$ ±10.50 | $85.6^{b}_{1}$ ±9.60 | $66.4^{ab}_{1}$ ±10.30 | $55.4^{bc}_{1}$ ±4.80 | $0.480^{a}_{1}$ ±0.051 | $0.503^{a}_{1}$ ±0.042 |
| 12 | $90.3^{b}_{1}$ ±6.40 | $72.9^{b}_{2}$ ±8.80 | $60.2^{b}_{1}$ ±6.30 | $46.7^{c}_{2}$ ±5.40 | $0.494^{a}_{1}$ ±0.049 | $0.514^{a}_{1}$ ±0.039 |

**Table 2. Effects of massaging time and drum speed on texture changes of SM muscle**
**a, numbers in columns, marked with identical superscripts are not significantly different within time massaging (P≥ 0.05)**
**1, numbers in columns, marked with identical subscripts are not significantly different among drum speed (P≥ 0.05)**

| Effective massaging time [h] | Hardness [N] | | Chewiness [N·cm] | | Cohesiveness [-] | |
|---|---|---|---|---|---|---|
| | 5 rpm | 20 rpm | 5 rpm | 20 rpm | 5 rpm | 20 rpm |
| 0 | $86.6^{a}_{1}$ ±9.31 | $86.6^{a}_{1}$ ±9.30 | $58.3^{a}_{1}$ ±5.70 | $58.3^{a}_{1}$ ±5.70 | $0.505^{a}_{1}$ ±0.059 | $0.505^{a}_{1}$ ±0.059 |
| 2 | $83.4^{ab}_{1}$ ±8.42 | $80.2^{abc}_{1}$ ±7.40 | $56.2^{ab}_{1}$ ±7.3 | $54.2^{a}_{1}$ ±6.80 | $0.498^{a}_{1}$ ±0.037 | $0.512^{a}_{1}$ ±0.062 |
| 4 | $79.5^{ab}_{1}$ ±7.88 | $72.3^{bc}_{1}$ ±4.30 | $54.1^{ab}_{1}$ ±6.90 | $48.4^{ab}_{1}$ ±7.42 | $0.508^{a}_{1}$ ±0.048 | $0.500^{a}_{1}$ ±0.038 |
| 6 | $74.3^{abc}_{1}$ ±8.20 | $63.2^{c}_{1}$ ±6.80 | $50.3^{abc}_{1}$ ±5.80 | $42.1^{b}_{1}$ ±4.25 | $0.502^{a}_{1}$ ±0.049 | $0.510^{a}_{1}$ ±0.054 |
| 8 | $70.1^{bc}_{1}$ ±6.20 | $51.8^{d}_{2}$ ±3.80 | $46.2^{bc}_{1}$ ±4.20 | $33.8^{c}_{2}$ ±3.87 | $0.509^{a}_{1}$ ±0.053 | $0.535^{a}_{1}$ ±0.047 |
| 12 | $61.2^{c}_{1}$ ±6.80 | $46.6^{d}_{2}$ ±4.22 | $41.8^{c}_{1}$ ±5.10 | $29.3^{c}_{2}$ ±4.11 | $0.518^{a}_{1}$ ±0.055 | $0.544^{a}_{1}$ ±0.049 |

Massaging resulted in a reduction of hardness and chewiness and in augmentation of cohesiveness, however the drum speed and time-dependent changes differed between the muscles. During the 12 h of effective massaging at 5 rpm drum speed, hardness and chewiness of SM decreased by about 30% and at 20 rpm drum speed - by about 50%, respectively. In this time textural parameters of BF decreased by about 20 and 35%, respectively. A significant differences in hardness of BF were recorded between massaged at 5 rpm drum speed and non-massaged control sample after 12 h effecive massaging on the one hand and SM after 8 h on the other. It can be concluded that the higher drum speed caused a higher reduction in hardness and chewiness in both of the muscles, however massage-induced changes in textural parameters were more extensive in SM than in BF. A similar effect of drum speed on pork's muscles texture, was presented by Lin et al. [14] and on turkey's muscles texture by Żych [34].

Among the samples tested, the highest time-dependent changes were shown – regardless of drum speed – by SM than BF. For this reason, to achieve a reduction of textural parameters in BF required longer massaging time, compared to SM. The highest rate of texture changes of SM was obtained between 6-8 h of effective massaging at 20 rpm drum speed, when the hardness reduction by about 18% was observed, while between 8-12 h of effective massaging – only by about 10%. In the same time, BF hardness decreased by as little as 8% and just between 8-12 h of effective massaging the rate of changes in BF picked up. Thus, the initially harder muscles required longer massaging and higher drum speed to attain a texture than did muscles showing initially lower hardness. As it shown by presented data (Table 1 and 2), to arrive at comparable textural parameters in both muscles, BF shoul be massaged for 12 h at 20 rpm drum speed and SM should be massaged for 8 h at 5 rpm or for 4 h at 20 rpm drum speed, respectively.

The correlation between cohesiveness vs massaging time and drum speed wasn't found. It was observed that longer-lasting massaged muscles or at higher drum speed showed higher cohesiveness, compared to the control samples (Table 1 and 2).

Differences in textural changes between ham muscles during massaging was presented by e.g. Boles and Shand [3], Lachowicz et al. [13], Rejt et al. [22]. The last authors found that, initialy less harder and springy QF and SM ham muscles were more susceptible to massaging than BF. It can be inferred that the swelling of myofibrilar proteins, and hence swelling of muscle fibres [18, 28] and loosening and damage of the connective tissue [19, 21], were responsible for the reduced hardness massaged meat. The increase in the cohesiveness, especially observed at 20 rpm drum speed, recorded in this study during massaging, may be an indication of a myofibrillar proteins extraction [17, 33]. That conclusions was corroborated by data placed at Table 3; long-lasting massaging, especially at high drum speed, caused an increase of exudate viscosity.

**Table 3. Effects of massaging time and drum speed on exude viscosity**
**a, numbers in columns, marked with identical superscripts are not significantly different within drum speed ($P \geq 0.05$)**
**1, numbers in columns, marked with identical subscripts are not significantly different among massaging time ($P \geq 0.05$)**

| Effective massaging time [h] / Drum speed [rpm] | 2 | 4 | 6 | 8 | 12 |
|---|---|---|---|---|---|
| 5 | $103.3^{a}_{1}$ ±8.20 | $136.6^{b}_{1}$ ±8.70 | $156.1^{bc}_{1}$ ±15.2 | $177.3^{c}_{1}$ ±14.7 | $204.8^{d}_{1}$ ±17.1 |
| 20 | $122.7^{a}_{1}$ ±12.4 | $150.8^{b}_{1}$ ±13.7 | $182{,}6^{c}_{1}$ ±17.8 | $250.8^{d}_{2}$ ±19.2 | $277.5^{d}_{2}$ ±20.3 |

The muscles studied were observed to differ significantly in their structural elements. The data of histological analysis of beef muscles, placed at Table 4 and 5 showed the non-massaged BF to have fibres of a higher mean cross-sectional area by about 45% and thicker peri- and endomysium by about 15 and 17%, than SM. A comparison between structural elements vs. textural parameters in both of non-massaged muscles allow to conclude that a muscle's hardness and chewiness increases with increasing fibre cross-sectional area and the thickness of connective tissue. Numerous authors, too, observed similar correlations between structural elements and texture of muscles e.g. Kłosowska et al. [9], Lachowicz et al. [12], Liu et al. [15], Oryl [20].

Massaging resulted in an increase of mean fibre cross-sectional area and peri- and endomysium changes of muscles, however the most extensive structural elements changes were stated in SM, irrespectively of time massaging and drum speed. A higher drum speed caused the most extensive structure changes; an increase by over twice in the mean fibre cross-sectional area of SM muscle and by about 56% in BF after 12 h of effective massaging were observed, compared to increased by about 60 and 24% at 5 rpm drum speed, respectively. The massage-induced changes in the mean cross-sectional fibre area at 5 rpm drum speed in both of the muscles were more extensive in muscles massaged effectively for 8 - 12 h. The higher rate of increase of mean fibre cross-sectional area being observed at 20 rpm drum speed in SM (by about 27%) and in BF (by about 17%) between 6-8 and 8-12 h of effective massaging, respectively.

No significant correlations between peri- and endomysium thickness changes during massaging were found, however an increase of connective tissue thickness being observed especially in SM over 6 h effective massaging at 20 rpm drum speed.

Increased mean cross-sectional area of muscle fibres is an evidence of their swelling, induced by mechanical forces and brine [8, 32]. The changes in connective tissue thickness, may be an indication of a damage and separations of fibrils [18, 33] and it's conductive to brine absorption by proteins [10, 28]. Thus it can be inferred that it was responsible for the fastest and more intensive fibre swelling in SM and in it's consequence a higher reduction of hardness during massaging, than in BF.

The longer-lasting massage as a higher drum speed resulted in fibre cross-sectional area changes; the shape of fibres became more and more round (Table 4 and 5). As shown by presented data, shape changes caused by brine sorption were especially visible in SM, the muscle to be more susceptible than BF to mechanical tenderisation.

**Table 4. Effects of massaging time and drum speed on mean values of BF structural elements**
**a, numbers in columns, marked with identical superscripts are not significantly different within time massaging ($P \geq 0.05$)**
**1, numbers in columns, marked with identical subscripts are not significantly different among drum speed ($P \geq 0.05$)**

| Effective massaging time [h] | Cross-sectional muscle fibre area [$\mu m^2$] | | Perimysium thickness [$\mu m^2$] | | Endomysium thickness [$\mu m^2$] | | Shape of muscle fibres [H diameter/V diameter] | |
|---|---|---|---|---|---|---|---|---|
| | 5 rpm | 20 rpm | 5 rpm | 20 rpm | 5 rpm | 20 rpm | 5 rpm | 20 rpm |
| 0 | $1250^{a}_{1}$ ±173 | $1250^{a}_{1}$ ±173 | $22.5^{a}_{1}$ ±2.21 | $22.5^{a}_{1}$ ±2.21 | $1.85^{a}_{1}$ ±0.15 | $1.85^{ab}_{1}$ ±0.15 | 0.929 | 0.929 |
| 2 | $1266^{ab}_{1}$ ±152 | $1329^{a}_{1}$ ±148 | $22.6^{a}_{1}$ ±2.37 | $23.0^{a}_{1}$ ±2.07 | $1.80^{a}_{1}$ ±0.20 | $1.78^{ab}_{1}$ ±0.13 | 0.935 | 0.938 |
| 4 | $1293^{ab}_{1}$ ±171 | $1418^{ab}_{1}$ ±182 | $22.8^{a}_{1}$ ±1.73 | $22.4^{a}_{1}$ ±1.96 | $1.78^{a}_{1}$ ±0.18 | $1.98^{a}_{1}$ ±0.10 | 0.940 | 0.929 |
| 6 | $1339^{ab}_{2}$ ±125 | $1532^{ab}_{1}$ ±147 | $22.5^{a}_{1}$ ±2.00 | $23.2^{a}_{1}$ ±2.48 | $1.85^{a}_{1}$ ±0.13 | $1.80^{ab}_{1}$ ±0.15 | 0.937 | 0.955 |
| 8 | $1420^{ab}_{1}$ ±204 | $1667^{bc}_{1}$ ±159 | $22.9^{a}_{1}$ ±2.38 | $23.9^{a}_{1}$ ±2.51 | $1.90^{a}_{1}$ ±0.17 | $1.92^{ab}_{1}$ ±0.22 | 0.942 | 0.962 |
| 12 | $1558^{b}_{1}$ ±94 | $1948^{c}_{2}$ ±167 | $23.0^{a}_{1}$ ±2.17 | $24.6^{a}_{1}$ ±2.11 | $1.95^{a}_{1}$ ±0.11 | $2.03^{ab}_{1}$ ±0.21 | 0.951 | 0.972 |

**Table 5. Effects of massaging time and drum speed on mean values of SM structural elements**
**a, numbers in columns, marked with identical superscripts are not significantly different within time massaging ($P \geq 0.05$)**
**1, numbers in columns, marked with identical subscripts are not significantly different among drum speed ($P \geq 0.05$)**

| Effective massaging time [h] | Cross-sectional muscle fibre area [$um^2$] | | Perimysium thickness [um] | | Endomysium thickness [um] | | Shape of muscle fibres [H diameter/V diameter] | |
|---|---|---|---|---|---|---|---|---|
| | 5 rpm | 20 rpm | 5 rpm | 20 rpm | 5 rpm | 20 rpm | 5 rpm | 20 rpm |
| 0 | $846^{a}_{1}$ ±103 | $864^{a}_{1}$ ±133 | $19.5^{a}_{1}$ ±1.77 | $19.5^{a}_{1}$ ±1.77 | $1.58^{a}_{1}$ ±0.13 | $1.58^{a}_{1}$ ±0.13 | 0.934 | 0.934 |
| 2 | $895^{ab}_{1}$ ±107 | $913^{a}_{1}$ ±108 | $19.3^{a}_{1}$ ±2.11 | $21.0^{ab}_{1}$ ±2.47 | $1.56^{a}_{1}$ ±0.19 | $1.62^{a}_{1}$ ±0.22 | 0.945 | 0.950 |
| 4 | $943^{ab}_{1}$ ±97 | $1004^{ab}_{1}$ ±123 | $20.4^{a}_{1}$ ±2.21 | $20.3^{ab}_{1}$ ±1.97 | $1.60^{ab}_{1}$ ±0.17 | $1.50^{a}_{1}$ ±0.25 | 0.951 | 0.948 |
| 6 | $1025^{b}_{1}$ ±112 | $1196^{b}_{2}$ ±92 | $19.6^{a}_{1}$ ±2.07 | $22.7^{ab}_{1}$ ±2.13 | $1.55^{a}_{1}$ ±0.22 | $1.70^{a}_{1}$ ±0.18 | 0.940 | 0.965 |
| 8 | $1168^{bc}_{1}$ ±118 | $1513^{c}_{2}$ ±138 | $20.8^{a}_{1}$ ±1.94 | $23.4^{b}_{2}$ ±1.98 | $1.61^{a}_{1}$ ±0.27 | $1.80^{a}_{1}$ ±0.24 | 0.959 | 0.983 |
| 12 | $1405^{c}_{1}$ ±139 | $1738^{d}_{2}$ ±163 | $21.4^{a}_{1}$ ±2.32 | $23.6^{b}_{1}$ ±2.13 | $1.70^{a}_{1}$ ±0.15 | $1.89^{a}_{1}$ ±0.13 | 0.973 | 0.989 |

**Table 6. Effects of massaging time and drum speed on thermal drip of BF and SM muscles**
**a, numbers in columns, marked with identical superscripts are not significantly different within drum speed ($P \geq 0.05$)**
**1, numbers in columns, marked with identical subscripts are not significantly different among massaging time ($P \geq 0.05$)**

| Drum speed [rpm] | | Effective massaging time [h]: 0 | 2 | 4 | 6 | 8 | 12 |
|---|---|---|---|---|---|---|---|
| BF | 5 | $33.8^{a}_{1}$ ±4.50 | $33.1^{a}_{1}$ ±4.10 | $32.4^{a}_{1}$ ±3.8 | $31.7^{a}_{1}$ ±2.9 | $31.0^{a}_{1}$ ±5.1 | $29.5^{a}_{1}$ ±4.2 |
| | 20 | $33.8^{a}_{1}$ ±4.50 | $31.7^{a}_{1}$ ±5.1 | $30.4^{a}_{1}$ ±4.2 | $28.4^{ab}_{1}$ ±3.9 | $26.2^{ab}_{1}$ ±4.7 | $21.5^{b}_{2}$ ±3.3 |
| SM | 5 | $29.3^{a}_{1}$ ±5.8 | $28,0^{a}_{1}$ ±3.6 | $26.7^{a}_{1}$ ±4.8 | $24.3^{a}_{1}$ ±5.1 | $21.5^{ab}_{1}$ ±3.2 | $16.2^{b}_{1}$ ±2.3 |
| | 20 | $29.3^{a}_{1}$ ±5.8 | $26.1^{ab}_{1}$ ±6.0 | $23.2^{ab}_{1}$ ±3.2 | $20.4^{b}_{1}$ ±2.1 | $15.3^{c}_{2}$ ±1.6 | $13.4^{c}_{2}$ ±1.7 |

The different susceptibility of the muscles studied to massaging was evidence also by differences in the amount of cooking loss produced by them (Table 6). The decrease in thermal drip in massaged meat was observed, the decrease being dependent both on time of massaging and on the drum speed, however the massaged SM, produced less thermal drip than that of BF. After 12 h of massage at 5 and 20 rpm drum speed, the reduction in thermal drip of the latter muscle amounted to about 13 and 36%, respectively, relative to the control; the SM thermal drip decreased by about 40 and 59%, respectively.

## CONCLUSIONS

To sum up, it can be concluded that:

- BF is characterised by fibres of a larger mean cross-sectional area as well as a thicker peri- and endomysium; it is also harder and more difficult to chew than SM
- the higher hardness and the coarser structure of BF slow down the rate of muscle fibre swelling
- for this reason, to achieve a significant reduction of hardness and chewiness BF required longer massaging time, compared to SM
- the effective massage during 12 h at 5 rpm drum speed did not result in any significant change in texture and structural elements in BF
- at the massaging regime applied in this study, to arrive at comparable textural parameters in the two muscles, BF should be effective massaged for 12 h at 20 rpm drum speed and SM - 8 h at 5 rpm drum speed or 4 h at 20 rpm drum speed.

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