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EFFECT OF OWN-CONSTRUCTION DEVICE FOR ELECTRICAL STIMULATION AND STORAGE TIME ON TENDERNESS OF BULLOCKS MEAT

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As a result of analyses of the effect of high voltage electrical stimulation (voltage of 330 V, frequency of 17 Hz, duration of 120 s) carried out *ca.* 40 min *after slaughter* on tenderness of bullocks (n=8) meat, lower values of the maximum shear force were obtained for the stimulated muscles (except for *semimembranosus* muscle stored for 144 h) as compared to its values noted for control muscles over the entire storage period. In addition, values of the maximum shear forces of stimulated, fresh *m. longissimus dorsi* and *m. semimembranosus* were alike and reached *ca*. 44 N. Results of analyses into the effect of storage time (144 h) on meat tenderness demonstrated that differences between the values of the maximum shear forces of the stimulated and control *m. semimembranosus* were decreasing along with time, whereas differences between the values of shear forces of *m. longissimus dorsi* (stimulated and control) were remaining at a constant level (*ca*. 30 N). The results obtained demonstrated that high voltage electrical stimulation, by means of an own-construction device, improves tenderness of the muscles examined.

INTRODUCTION

The quality of meat and its products is determined, most of all, by the quality of raw material. However, obtaining high quality material is extremely difficult as it depends on a variety of both *ante-mortem* and *postmortem* factors [Polidori *et al*., 1996]. Out of a number of the intravital factors, of significance is sex of animals which affects differentiation of muscles in terms of composition, structure and distribution of muscle fibres. Meat of bull calves is characterized by a better ratio of muscles to connective tissue, as compared to that of heifers, yet their impulsive temperament and susceptibility to pres-slaughter stress contribute to the occurrence of quality faults, *e.g.* DFD [Wajda, 2001].

Investigations carried out so far have led to implementation into the production process of multiple microbiological, biological, chemical and physical methods that, to a greater or lesser extent, enable modeling the quality of meat [Pospiech, 2003]. Physical methods are acknowledged as the most recognized and most often applied methods for improving meat quality. They consist in thermal or mechanical provision of kinetic energy to a system (carcass), thus affecting the structure of muscle tissue. One of such methods is electrical stimulation which consists in a short-term effect of electric current, imitating nervous impulses, on muscle tissue of carcass (half-carcass) in the first hour *postmortem*, thus evoking a number of processes comparable with those proceeding in a live organism. Improvement of beef tenderness is achieved by means of: accelerated decomposition of glycogen under elevated temperature, elimination of the phenomenon of cold shortening and by increasing the activity of lysosomal enzymes stimulating the process of meat tenderization [Ho *et al*., 1997; Hwang *et al*., 2003].

Taking into account the value of voltage, electric stimulation has been conventionally divided into: extra low voltage (up to 40 V) – ESENN, low voltage (up to 100 V) – ESNN, and high voltage (from 100 to 3600 V) – ESWN. Due to economical reasons and safety at work, the ESNN is more attractive to the meat industry, however its effect on meat tenderness is weaker than that of ESWN. It results, among other things, from the optimal rate of *postmortem* changes (pH=6.0–6.1 in the third hour *postmortem*), which is not possible upon the use of the ESNN [Dransfield, 1992; Lesiow, 1993; Żywica, 1999]. Hwang & Thompson [2001], in comparing the impact of ESNN and ESWN on tenderness of *m. longissimus dorsi*, depending on the time span of the treatment (after 3, 40 and 60 min *postmortem*), found that the high voltage electrical stimulation evoked an improvement in meat tenderness by 28 to 40%, whereas in the case of the low voltage electrical stimulation the improvement in meat tenderness was considerably smaller and ranged from 8 to 17%, respectively.

Elucidation of the mechanism of *postmortem* changes and factors determining them during technological processes does not allow for explicit statements on the effects of electrical stimulation exerted on changes in quality traits of meat subjected to various technological processes. Thus, taking all these into account, a study was undertaken to determine the

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effect of high voltage electrical stimulation, by means of an own-construction device, and time of chill storage on tenderness of bull calves meat.

MATERIAL AND METHODS

The experimental material was meat of bullocks (*longissimus dorsi* and *semimembranosus* muscles) of the lowland black-white breed at the age of *ca*. 18 months (n=8). The cattle was slaughtered after *ca*. 12-h rest in a lairage and watering with a 2% solution of molasses.

The experiment consisted in the stimulation of left half-carcasses with an electric current with: voltage of 330 V, frequency of 17 Hz, pulse duty factor of 0.9, rectangular pulse, for 120 s, *ca*. 40 min after stunning. The electrical stimulation was carried out by means of an own-construction device [Żywica *et al*., 1997], which has been implemented in the Meat Plant "Ostrołęka S.A." in Ostrołęka and awarded a golden medal at the 45th International Exhibition of Inventions and Innovations "Brussels Eureka 96" in Brussels. The right half-carcasses constituted a control, not-stimulated, sample. The carcasses were cooled with air at a temperature of 0–2°C. Measurements of pH were performed *ca*. 40 min, 2, 6 and 24 h after stunning with the use of an HI 8314C pH--meter equipped with a spike electrode FC 200. After *ca*. 24 h from stunning, the muscles were trimmed and divided into pieces weighing *ca*. 300 g each. A part of the muscles (fresh meat) was closed hermetically in metal boxes and subjected to pasteurization at a temperature of 72°C for 90 min. The other part of the muscles was packed in polyethylene bags and stored in an air conditioned chamber (air temperature of *ca*. 4°C) for 144 h and also subjected to the pasteurization process. The thermally-preserved product was chilled in water and then stored in a cooler at a temperature of 4°C until analysed (maximally up to 14 days). Thermal drip was determined with the gravimetric method from the difference between the mass of meat before and after the thermal treatment, and expressed in per cent of the mass of raw material prior to processing.

Instrumental evaluation of meat tenderness was carried out with the use of a universal testing machine Instron, type 4301, after 0 (24 h *after slaughter*) as well as 72 and 144 h of storage. Shearing test was carried out with a Warner-Bratzler single-blade shearing system, type 2830-013 (blade angle 60°, knife thickness 1.016 mm), with the knife moving perpendicularly to the orientation of muscle fibers and speed of working elements reaching 50 mm/min. The following parameters were measured: the maximum shear force (F_{max}) and deformation at the maximum shear force (D). Results of the test were analysed with a computer using Instron IX Series ver. 7.43 software [Giese, 1995]. Measurements of the above-mentioned parameters were performed in 4 replications for each sample. Temperature of the samples during the test accounted for *ca*. 21°C.

A statistical analysis of the results obtained was carried out based one-way and two-way analysis of variance. Duncan's test and Student-Newman-Keuls test were used to compared the mean values obtained [Taylor, 1995]. Calculations were made with Excel and Statistica softwares.

RESULTS AND DISCUSSION

The experiments conducted indicated that, as a result of applying electrical stimulation, the greatest decrease of pH, by 1.05 units on average, occurred in *m. semimembranosus* within the first 2 h after stunning. In the subsequent 4 h, pH dropped to 5.78, *i.e.* by 1.17 units on average. After 24 h from stunning, pH of that muscle reached 5.74 and was the lowest amongst all final values obtained as a result of electrical stimulation of half-carcasses. Mean declines in pH of the *m. semimembranosus* in the control half-carcasses accounted for: 0.55, 0.87 and 1.19, respectively. As compared to the stimulated *m. semimembranosus*, lower declines of pH were obtained in the stimulated *m. longissimus dorsi*. In the first 2 h, its pH decreased by 0.92 units, whereas after the subsequent 4 h (6 h after slaughter) and 22 h, it dropped by 1.12 and 1.25 units, respectively. Decreases in pH values of the control muscles in the above-mentioned time intervals reached: 0.46, 0.85 and 1.22 units, respectively (Table 1).

The presented changes in pH of the muscles examined as well as its low final values indicate that meat of bullocks demonstrated the final pH typical of normal meat and comparable with pH of heifers of the same breed, stimulated under the same conditions but with a different device [Żywica *et al*., 1995; Żywica, 1999]. It results from the applied 12-h pre-slaughter rest and watering the animals with a 2% solution of molasses [Wajda, 1994]. According to a number of scientists [Polidori *et al*., 1996; Żywica, 1999; Hwang *et al*., 2003], a rapid decline of pH within the first 2 h after slaughter, at a relatively high temperature of muscles, and – owing to this – avoidance of the phenomenon of cold shortening as well as structural changes of the muscle tissue induced by the

TABLE 1. Results of pH measurements of *m. longissimus dorsi* and *m. semimebranosus* of bullocks after slaughter.

Experimental material	*M. longissimus dorsi*				*M. semimebranosus*			
	S		K		S		K	
Statistical measures	$\bar{x}$	V (%)	$\bar{x}$	V (%)	$\bar{x}$	V (%)	$\bar{x}$	V (%)
pH_0	7.02^a	1.24	7.01^a	1.21	6.95^a	1.14	6.97^a	0.92
pH_2	6.10^b	1.18	6.55^b	1.17	5.90^b	1.23	6.42^b	0.99
pH_6	5.90^c	1.53	6.16^c	1.41	5.78^c	1.08	6.10^c	1.25
pH_{24}	5.77^d	1.02	5.79^d	1.70	5.74^d	1.78	5.78^d	1.36

$\bar{x}$ – mean value; V – coefficient of variation; S – stimulated muscles; K – control muscles; pH_0 – pH of muscles *ca*. 40 min (2/3 h) after slaughter; $pH_{2, 6, 24}$ – pH of muscles 2, 6 and 24 h after slaughter; F_{max} – maximum shear force; D – deformation at the maximum shear force; $^{a-c}$ – mean values denoted in columns with different letters are statistically significantly different ($p<0.01$); * – differences significant in rows ($p<0.05$); ** – differences significant in rows ($p<0.01$)

flow of electric current, constitute the major cause of improving tenderness of beef exposed to electrical stimulation. An additional argument confirming the above statement is the fact that those mechanisms proceed during electrical stimulation simultaneously. Moreover, the obtained rate of *post-mortem* changes indicates that after 2 h (between the 2nd and 3rd hour after the slaughter), pH of the stimulated muscles ranges from 5.9 to 6.1, which – according to Drobisz [1994] and Polidori *et al*. [1996] – points to a moderate rate of glycolysis and a beneficial effect of electrical stimulation on beef tenderness.

Results of the instrumental analysis of tenderness demonstrated that the values of the maximum shear force (F_{max}) of the stimulated muscles (except for *m. semimembranosus* stored for 144 h) were lower than those reported for the control muscles over the entire storage period (Tables 2 and 3). Along with storage time proceeding (0–144 h), F_{max} values of *m. longissimus dorsi* – both the stimulated (45.13, 32.07, 27.61 N) and the control one (74.73, 63.84, 55.24 N) – were observed to decrease. In the case of the control samples, a decline in F_{max} values was accompanied by an increase in the value of deformation (2.78, 3.36, 3.94 mm), whereas in the case of the stimulated muscles – values of meat sample deformation were remaining at a similar level of *ca*. 3.40 mm (Table 2).

Storage of *m. semimembranosus* for the period of 72 h evoked a decrease in the F_{max} value of the stimulated sample from 44.40 to 36.80 N and in that of the control sample – from 57.25 to 46.25 N. After 144 h of storage, the F_{max} value of the stimulated samples increased to 39.24 N, whereas that of the control sample – decreased to 34.83 N. In the above-mentioned time interval, deformation (D) value of the stimulated muscle dropped from 3.26 to 3.13 mm, and next increased to 3.92 mm. In the case of the control muscle, the D value first increased from 3.67 to 4.11 mm and then dropped to again 3.67 mm (Table 3).

The statistical analysis of the results of the study aimed at determining the effect of electrical stimulation on tenderness of *m. longissiums dorsi* of bullocks indicated significant differences ($p \leq 0.01$) in the values of the maximum shear force between the stimulated and control samples, irrespective of the time of storage. Deformation values of samples of the stimulated and not-stimulated muscles differed statistically ($p \leq 0.01$) only in the case of the fresh muscle. Significant differences ($p \leq 0.01$) were observed between the F_{max} values of the stimulated and fresh not-stimulated *m. semimembranosus* stored for 72 h after slaughter. The F_{max} value of the stimulated and not-stimulated muscle stored for 144 h were not significantly different. In contrast, the D values of the stimulated and not-stimulated muscles stored for 72 h and fresh muscles differed significantly – $p \leq 0.01$ and $p \leq 0.05$ (Tables 2 and 3).

The statistical analysis of the results of the experiment aimed at determining the effect of storage time on tenderness of bullocks meat demonstrated significant differences ($p \leq 0.01$) between the values of the maximum shear forces (F_{max}), over the entire storage period, only in the case of not-stimulated *m. semimembranosus*. Significant differences ($p \leq 0.01$) between the F_{max} values of meat stored for 72 h and those noted for the fresh meat were obtained for the stimulated and not-stimulated *m. longissimus dorsi* as well as for the stimulated *m. semimembranosus*. Significantly different were also the F_{max} values of the stimulated and not-stimulated *m. longissimus dorsi* stored for 144 h and fresh. No significant differences were obtained between the F_{max} values of the stimulated and not-stimulated *m. longissimus dorsi* and stimulated *m. semimembranosus* during storage from 72 to 144 h as well as between the values of that parameter noted for the stimulated *m. semimembranosus* stored for 144 h and fresh

TABLE 2. Effect of electrical stimulation and storage time on tenderness of *m. longissimus dorsi* of bullocks.

Experimental group		S		K		S–K
Statistical measures		$\bar{x}$	V (%)	$\bar{x}$	V (%)	F_{emp}
Storage time, 0 h	F_{max} (N)	45.13[a]	11.41	74.73[a]	10.18	103.78**
	D (mm)	3.43[a]	10.48	2.78[a]	15.29	13.51**
Storage time, 72 h	F_{max} (N)	32.07[b]	13.56	63.84[b]	11.86	132.41**
	D (mm)	3.57[a]	7.42	3.36[ab]	18.12	0.92
Storage time, 144 h	F_{max} (N)	27.61[b]	7.40	55.24[b]	15.96	93.27**
	D (mm)	3.20[a]	36.40	3.94[b]	13.93	3.27

Explanations as in Table 1

TABLE 3. Effect of electrical stimulation and storage time on tenderness of *m. semimebranosus* of bullocks.

Experimental group		S		K		S–K
Statistical measures		$\bar{x}$	V (%)	$\bar{x}$	V (%)	F_{emp}
Storage time, 0 h	F_{max} (N)	44.40[a]	9.92	57.25[a]	7.38	43.63**
	D (mm)	3.26[a]	10.53	3.67[a]	8.78	7.60*
Storage time, 72 h	F_{max} (N)	36.80[b]	12.52	46.25[b]	10.95	19.05**
	D (mm)	3.13[a]	7.31	4.11[a]	13.66	25.94**
Storage time, 144 h	F_{max} (N)	39.24[ba]	11.41	34.83[c]	20.87	2.67
	D (mm)	3.92[b]	10.16	3.67[a]	12.69	1.60

Explanations as in Table 1

meat (Tables 2 and 3). In the case of meat samples deformation (D), significant differences were obtained between the values of that parameter reported for meat samples of stimulated *m. semimembranosus* stored for 72 h and D values of that muscle stored for 144 h as well as for the control samples of *m. longissimus dorsi* stored for 144 h after slaughter and samples of fresh meat (Tables 2 and 3).

Results of analyses of thermal drip obtained for the stimulated *m. longissimus dorsi* demonstrated that its values were smaller than those noted in the control muscles (except for meat examined directly after trimming) and were decreasing from 27.33 to 25.00% along with the time of storage. Thermal drips of the stimulated *m. semimembranosus* were smaller than those of the control muscle, irrespective of storage time. With the storage time proceeding, thermal drips of the control *m. longissimus dorsi* (25.00, 30.13, 32.12%) and stimulated *m. semimembranosus* (26.58, 30.46, 30.69%) were observed to increase, whereas thermal drops of the not-stimulated *m. semimembranosus* decreased from 32.56 to 32.12% after 72 h of storage and next, after 144 h of storage, were found to increase to 33.77% (Figure 1).

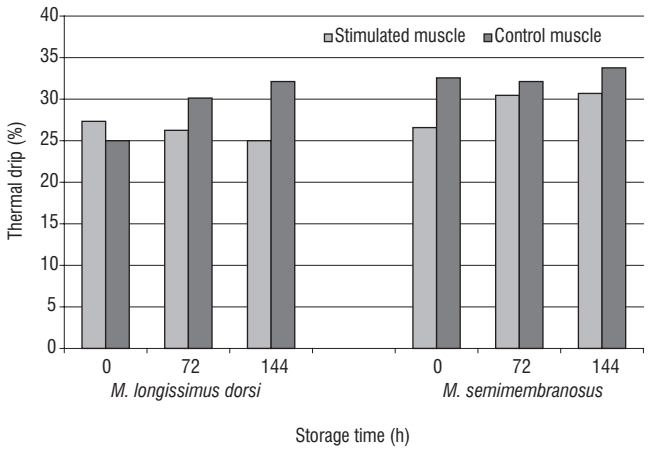

FIGURE 1. Thermal drip of *m. longissimus dorsi* and *m. semimembranosus* of bullocks depending on the time of storage.

Smaller thermal drips from the stimulated muscles, as compared to those from the control muscles were also reported by Tkacz [1999] who applied thermal treatment to fresh meat. In turn, Powell [1991], while investigating the effect of electrical stimulation on the size of storage drip, obtained smaller mass losses of the stimulated *m. longissimus dorsi* originated from young animals and trimmed 24 h after slaughter, as compared to losses of the mass of the stimulated muscle.

Assuming that there exists a statistical correlation between sensory assessment of tenderness and the maximum shear force (at the knife cut perpendicularly to the orientation of muscle fibres), it can also be concluded that electrical stimulation improves, to a great extent, one of the key textural traits, *i.e.* tenderness [Beilken *et al*., 1991; Cierach & Majewska, 1997]. Thus, in analysing the effect of electrical stimulation, the type of muscle and period of its storage on beef tenderness it should be stated that *ca*. 24 h after slaughter (0 h of storage) tenderness of the stimulated *m. longissimus dorsi* and *m. semimembranosus* was alike, yet tenderness of *m. longissimus dorsi* was better by *ca*. 40% whereas that of *m. semimembranosus* was better by *ca*. 20% than that of the respective control muscles. This indicates that high voltage electrical stimulation enables the production of beef with equal tenderness, irrespective of the type of muscle [Powell, 1991; Dransfield *et al*., 1992]. The results of tenderness analysis demonstrate that the improvement of tenderness of bullocks meat is smaller than that of the meat of heifers (47%) of the same breed slaughtered under the same conditions and stimulated with the same device [Żywica, 1999], and higher as compared to the improvement of tenderness of stimulated *m. longissimus dorsi* of heifers (32% and 21%) reported by Ostoja & Korzeniowski [1992] and Szorc [1984], respectively.

Along with the time of storage, differences in the improvement of tenderness of meat of *m. longissimus dorsi* were increasing (39.61, 49.8%) and after 144 h reached *ca*. 50%. In contrast, differences in the improvement of *m. semimembranosus* tenderness during storage were observed to decrease (22.44, 20.43%) and after 144 h were negligible – 12.66% (statistically insignificant). Similar findings were also reported by such authors as Taylor & Cornell [1985] and Eilers *et al*. [1996]. They demonstrated that electrical stimulation affected acceleration of beef ageing and improvement of its tenderness, and that along with storage time proceeding differences between tenderness of stimulated meat and that not subjected to that treatment are blurring. In addition, the process of *postmortem* changes and, consequently, the process of *m. semimembranosus* tenderization proceeds much faster than those of *m. longissimus dorsi*. This results from, among other things, the anatomical structure of muscles (thickness of membranes, number of thick and thin fibers and their spatial arrangement) and their location in the carcass [Morgan *et al*., 1991]. This has also been confirmed by greater thermal drips from *m. semimembranosus* during storage as compared with thermal drips of both stimulated and control *m. longissimus dorsi*.

CONCLUSIONS

1. The device and parameters of stimulation applied in the study enable obtaining a proper rate of the glycolysis process (2 h after stunning, mean pH=6.0), which had a positive impact on meat tenderness.

2. The improvement of *semimembranosus* muscle tenderness declining with time as well as that of *longissimus dorsi* muscle increasing with time indicate that the rate of ageing process and, consequently, the course of changes in tenderness of bullocks meat in the process of refrigerated storage are determined by the type of muscle.

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WPŁYW WŁASNEJ KONSTRUKCJI URZĄDZENIA DO ELEKTROSTYMULACJI I CZASU PRZECHOWYWANIA NA KRUCHOŚĆ MIĘSA BUHAJKÓW

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W wyniku badań wpływu elektrostymulacji wysokonapięciowej (napięcie 330 V, częstotliwość 17 Hz, czas trwania 120 sekund) przeprowadzonej po ok. 40 min. od uboju, na kruchość mięsa buhajków (n = 8) uzyskano mniejsze wartości maksymalnej siły cięcia mięśni stymulowanych (z wyjątkiem mięśnia półbłoniastego przechowywanego przez 144 h) od wartości tej wielkości mięśni kontrolnych w całym okresie przechowywania. Ponadto wartości maksymalnych sił cięcia mięśnia najdłuższego grzbietu i półbłoniastego stymulowanego, świeżego były do siebie zbliżone i wynosiły ok. 44 N (tab. 2, 3). Wyniki badań wpływu czasu przechowywania (144 h) na kruchość mięsa wykazały, że różnice między wartościami maksymalnych sił cięcia mięśnia półbłoniastego stymulowanego i kontrolnego zmniejszały się w miarę jego upływu (tab. 3), natomiast różnice między wartościami maksymalnych sił cięcia mięśnia najdłuższego grzbietu (stymulowanego i kontrolnego) utrzymywały się na stałym poziomie (ok. 30 N) – tab. 2. Na podstawie uzyskanych wyników stwierdzono, że elektrostymulacja wysokonapięciowa, z zastosowaniem urządzenia własnej konstrukcji, poprawia kruchość badanych mięśni. Ponadto szybkość procesu dojrzewania i tym samym szybkość procesu skruszania mięsa buhajków w czasie jego przechowywania zależy od rodzaju mięśnia oraz prawdopodobnie od jego budowy anatomicznej i umiejscowienia w tuszy.