WFL Publisher
Science and Technology
Meri-Rastilantie 3 B, FI-00980
Helsinki, Finland
e-mail: info@world-food.net

Journal of Food, Agriculture & Environment Vol.7 (3&4) : 101-105. 2009 *www.world-food.net*

Effects of electrical stimulation on meat quality in goat carcasses

Ömer Cetin * and Tuna Topcu
*Department of Food Hygiene and Technology, Faculty of Veterinary Medicine, Istanbul University, 34320 Avcilar, Istanbul, Turkey. *e-mail: omce@istanbul.edu.tr*

Received 22 July 2009, accepted 6 October 2009.

Abstract

Considering the common use of electrical stimulation in meat technologies, it was conducted a study with 10 female goats, in order to determine its effect on improving quality criteria. The goats, kept in the rest period before slaughtering, were stunned and exsanguinated. The subjects were cut into halves through median lines. The right halves were applied 50 Hz, 1.5 minutes long, 30 or 100 Volts of electrical stimulation (ES) and the left halves were kept as control group. The carcasses were studied in +4ºC stable refrigerator conditions for 7 days and pH, water activity, water holding capacity, drip loss, shear force, color, sensory panel values and total aerobic mesophilic bacterial count values were measured. Our findings showed that ES introduced faster decrease and lower values of pH decline compared to the control group. The application implemented lower values of water holding capacity, yet no significant difference between groups was found. The application had a negative impact on water activity and an increase was observed after the ES. ES increased the drip loss but only 1st and 7th days results were found to be highly significant ($p<0.001$) between ES and control groups. Significant differences of shear force values were measured between ES and control groups on the 7th day ($p<0.05$). For the color measurement ES improved the color criteria, yet only significant difference was found for the *L** value on the 7th day ($p<0.01$). The total aerobic mesophilic bacterial count values indicated a positive influence of ES, but only for the *Longissimus* muscle significant differences were observed ($p<0.01$). For both raw and cooked sensory panel values it was observed that, ES had an positive impact on quality criteria. Also significant differences for raw sensory panel values were measured ($p<0.01$). In conclusion, our study showed that low voltage electrical stimulation is a useful method for improving quality criteria of goat meat.

Key words: Electrical stimulation, water activity, drip loss, shear force, color.

Introduction

Considering meat consumption, quality characteristics, such as color, tenderness and taste, have an important effect on customer satisfaction. In order to improve the quality of the meat for a better customer satisfaction, physical, chemical and microbiological methods are applied to the meat either in carcass form or boneless meat [1]. For this purpose, vegetable enzymes, such as papain, bromelain and ficin, proteolitic enzymes obtained from some fungus such as *Sarcodon aspratus* [2] and from some bacteria such as *Bacillus* spp., elastase are used [3]. Another one of these applications is electrical stimulation, which is applied to the carcasses and boneless meat immediately after the slaughter.

The electric current flowing through the muscle tissue causes pH decline by increasing post mortem glycolysis [4,5]. It also partially decreases the microbial total count of the carcasses [6] by preventing cold shortening and improving some quality parameters such as color, shear force and flavour [7,8].

Although goat meat is a good source of protein just like other kinds of butcher's meat, its fat content is lower than that of lamb. Therefore, it is prefered by the conscious consumers to beef, lamb and pork. On the other hand, there is a common opinion that goat meat's flavour is poorer than other kinds of meat [9]. Increasing maturity and old age reduces the desired flavour and causes toughness. Improving the tenderness of such carcasses may improve their marketing opportunities by increasing the retail price[10].

There are several studies on stimulating butchery carcasses with high and low electrical voltages [11,12]. Many researchers [13-15] reported that low voltage electrical stimulation applications prevents cold shortening, improves tenderness and declines pH.

For the purpose of determining the effects of low voltage electrical stimulation applications on lamb, five minutes after the slaughter, Polidori *et al*. [15] performed electrical stimulation (ES) application of 28 V 60 Hz for one minute duration, to 24 Rambouillette lamb carcasses. ES was applied to the carcasses after they were kept in the chilling room. Samples from *Longissimus* and *Semimembranosus* muscles of the control group were taken to be analyzed in terms of the quality of meat. *Semimembranosus* and *Longissimus* muscles get tender in the seventh day and between 2-7 days, respectively.

Wiklund *et al.*[16] applied ES of 80 V, 70 Hz for 20 seconds of duration, five minutes after the slaughter, to different forms of meat obtained from 26 carcasses of over 3-years-old castrated reindeers. Immediately after the ES application, the meats were deboned. It was reported in the study that the tenderness of the sliced and cubed meat from the shoulder were improved.

Biswas *et al.* [6] studied the effects of electrical stimulation in different voltages on goat carcasses. For this purpose, 35, 110, 330, 550 and 1100 V with fixed 50 Hz electrical current were applied to the carcasses of 30 male Black Bengal Goats between 5-8 years of age for three minutes. In the samples from the electrically stimulated carcasses, sarcomere length was increased, fibre

diameter, pH and water holding capacity were declined. According to the sensory panel tests, electrically stimulated muscles were reported as more tender than the control group.

The aim of this study was the investigation of the changes in the quality criteria of goat meat caused by low voltage electrical stimulation.

Materials and Methods

Materials: Ten female Malta Goat between 2-5 years old, which are at the same age period, same breed, and are subjected to the same feeding process, were processed by the approval of the Institute of Health Sciences (Approval number: 06/13.02.2008).

Preslaughter and slaughtering process: One day before the slaughter, the animals were held in different shelters, and they were kept without feed and water 12 and 6 hours, respectively, before slaughter, in order to prevent any kind of negativity about slaughtering hygiene. After the rest period, the goats were put through health detection and sent for slaughter without stress.

The animals were stunned applying 20-250 V, 1.0–1.3 A and 1–3 seconds of electroshock, and then carefully about the hygiene, bleeding was performed. Following the dressing and eviscreation processes, the carcasses were halved by splitting along the vertebral column, and the right sides were kept for ES treatment.

Postslaughter electrical stimulation treatment: In order to examine the effects of ES, approximately at the 30-45th minute of the post-mortem after slaughter, electrical stimulation of 50 Hz was applied for 1.5 minutes, to the right side of goat carcasses, which were previously splitted along the median line when one of the electrical current clamps of 30 and 100 Volts were attached to the neck, and the other to the hind limb. Left sides of the carcasses, which were not electrically stimulated, were assigned as the control group. Following the ES treatment, the half carcasses were moved to the chilling room, and 18-24 hours after the slaughter, they were separated according to their muscle groups. After *Longissimus* muscles of the electrically stimulated and the control groups were removed, the meat were put through microbiological (total aerob bacterial amount), sensory (color, savour flavour, appearance, toughness) and physicochemical (instrumental color, Warner-Bratzler shear force, pH, water holding capacity, water activity value, drip loss) analysis.

Physicochemical analysis: At 1, 3, 6, 12 and 24 h of postmortem, pH was measured using a pH-meter with an appropriate probe in the internal parts of the carcasses.

Following the slaughter, the carcasses were weighed as a whole on the 0, 1, 3 and 7 days while they were kept in the fridge at 4°C. Thereby, the drip loss was evaluated by subtracting the values from the previous day's values using a digital scale [17].

To measure the water holding capacity 300 mg meat samples were collected from control and treated sides of the carcasses on the 1, 3 and 7 days of the postmortem phase and placed on Whatman No.1 filter paper. The samples were kept between glass slips, and under a fixed weight of 1 kg for 20 minutes. At the end of the waiting period, the filter paper was taken. The impressions released by the water were measured using millimetric paper and calculated by appropriate formulas [18]. Water holding capacity = Range of dispension (cm^2)/total area (cm^2)

Water activity measurements of the samples from each carcass halves were carried out using a water activity device (hygrometer) on 0, 1, 3 and 7 days of postmortem period [17].

For Warner-Bratzler shear force analysis the samples from *M.longissimus dorsi* were measured on the 1, 3 and 7 days by using Instron device and Warner-Bratzler shear force system [19].

Color analysis was carried out for the samples taken on the 1, 3 and 7 days of postmortem phase. First, the samples were cleaned from fascia and fat and cut into small pieces. The device was calibrated with black, white and green frames before using. ColorFlex Hunter Lab Color Measurement System (Hunter Associates Laboratory, Inc., ABD) was used according to CIE *L*a*b** values, and the average of the five resulting values was taken [16].

Microbiological analysis: Swaps from shoulder, back, loins and longissimus dorsi muscles of the carcass halves were taken as samples on the 0, 1, 3 and 7 days of post mortem. For the total mesophyll aerobic bacteria count, spill plantation was done into Plate Count Agar (PCA, Merck 1.05463), and after the incubation period of 48 hours at 37°C, all the proliferated were counted [20].

Sensory analysis: The sensory analysis of the samples from goat meat was performed by a panelist group of five people on the 1, 3 and 7 days of post mortem. Within the scope of evaluation of the samples, the raw and the cooked were graded separately. While color, savour, appearance and tenderness were the considered criteria for the raw samples, for the cooked ones, flavour was also considered, and each one was graded out of 10. Cleaned from their fascia and fat, the meat were cooked in a fixed-temperature-oven until their inner temperature was 75ºC. After each group was graded, their averages were taken [21].

Statistical evaluation: The results from microbiological, physicochemical and sensory analysis, which were obtained from the experiments on goat meat, were evaluated statistically by SPSS General Linear Model Comparison Test [22].

Results and Discussion

The pH values obtained from carcass halves through the measurements at the 1, 3, 6, 12 and 24 h are given in Table 1. According to these results, it was found that the pH values obtained from electrically stimulated carcass halves were lower than the ones from the control group, and they had a more rapid falling progress. However, significant difference was observed not between the electrically stimulated and the control groups but between the days.

Results similar to our findings were also obtained by Strydom *et al.* [1]. Ten Charolais breed sheep were slaughtered and the left sides were stimulated by 400 V electrical current for 45 seconds, while nothing was applied to the right sides. The carcasses were chilled under normal conditions. Results show that pH reached the values 6.2–6.0 rapidly. Biswas *et al.* [6] reported in their study on goats that significant improvement was observed on carcasses electrically stimulated with different voltages (35, 110, 330, 550, 1100) and 50 Hz frequency.

Wiklund *et al.* [16] used 26 male reindeer in their study, and they performed the treatment with 80 V. Although pH decline was observed in their results from *M. Longissimus dorsi* and *M. Biceps*

Table 1. Average and standard errors of the pH values measured in muscles.

Treatment	0 hour	3rd hour	6th hour	12th hour	24th hour
ES 30	6.60 ± 0.118	6.50 ± 0.143	6.40 ± 0.144	6.20 ± 0.255	5.80 ± 0.161^{b}
ES100	6.55 ± 0.118	6.40 ± 0.143	6.30 ± 0.144	6.10 ± 0.255	5.70 ± 0.161^{b}
Control	6.65 ± 0.083	6.55 ± 0.101	6.55 ± 1.102	6.45 ± 0.181	6.30 ± 0.114^{a}
Average	6.60 ± 0.062 ^{A}	6.48 ± 0.075 ^{AB}	6.41 ± 0.076 ^{AB}	6.25 ± 0.135 ^{B}	5.93 ± 0.085 ^{C}
p	NS	NS	NS	NS	**

^{a,b}: The difference between the mean values having a different letter at the same column is statistically important. [(*): $p < 0.05$ (**): $p < 0.01$] NS Statistically not significant ($P > 0.05$), Control: control group, ES Stimulation treatment A.B: The difference between the mean values having a different letter at the same row is statistically important.

femoris, this decline was only around 0.07. Zywica *et al.* [23] observed in their study on young bulls that the softening of *Longissimus dorsi* muscle and the decline in pH values were at a significant rate. Considering pH values, as the statistical calculations approve, it is observed that there is no correlation between the amount of the electrical current and the carcass mass.

The effects of low voltage ES treatment on small ruminant carcasses to the quality of meat was studied by Kahraman [24]. The ES treatment was carried out with two different voltages (50 and 100 V) and 100 Hz for two minutes to the right sides of the carcasses, and the left sides was kept as the control group. After the treatment, samples were taken from *M. longissimus dorsi* muscle, and the required analysis were performed in order to determine the quality of the meat. A rapid pH decline was observed in the electrically stimulated meat compared to the control group. Ferguson *et al.* [4] electrically stimulated 22 merinos breed sheep with 300 V for 20 minutes. The results they reached showed that although diet was not effective, ES caused a significant difference in pH decline.

It has been observed that the drip loss amount obtained from the ES-treated carcass halves is greater than from the control group. High amount of significant difference ($p<0.01$) has also been observed statistically both between the measurement days and between the treatment groups. Taylor *et al.* [25] electrically stimulated the left halves of 36 pigs weighing 70-80 kg with 35 V and 14 Hz for 64 seconds to obtain results in agreement with ours. Channon *et al.* [26] treated 48 female pigs in two of their studies. Different from the results we have obtained, in the first of those studies, they reported that ES did not affect the drip loss, while in the other [27], they reported that the drip loss was not only affected by ES, but also increased by the rising voltage. In the study by Bond *et al.* [28] on 40 sheep, the treatment was carried out with 200 V and with the nostral ring and the rectal probe in the fifth minute. Their results showed that ES did not change the drip loss.

Water holding capacity values, with respect to the statistical averages, did not reach the results which show significant differences between neither different days nor ES and NES grups on the same day. Biswas *et al.* [6] reached results similar to ours with their study on Bengal goats at the age of 5-8. They separated the goats into five groups, and electrically stimulated them with 35, 110, 330, 550 and 1100 V, respectively. The samples showed significant differences ($p<0.05$) with respect to water holding capacity in electrically stimulated ones since pH decreases water holding capacity. Strydom *et al.* [1] ES treated the left sides of 10 cholaris breed with 400 V at the 45th minute. Their results showed that the water holding capacity was lower than in the control group although no significant difference was observed. Similarly, Li *et al.* [29] treated 28 bulls with 24 V and 50 Hz ES, and when they observed in different chilling conditions, they saw that although ES has negative effects in terms of water holding capacity, this effect could be improved using rapid chilling conditions. Rosenvold *et al.* [30] also reached similar results in their study.

Water activity values appear in electrically stimulated carcass halves were higher than the control groups. In this study, water activity values from the group treated with ES100 and the control group show significant difference ($p<0.05$), as well as the values measured in different days. Different from our research, Kahraman[24] did not observe any significant difference between the control group and 20 ES-treated carcasses.

The shear force values obtained from the electrically stimulated carcass halves were lower than in the control group (Table 2). Considering the voltage groups in our study, only the ES100 was significantly different from the control group ($p<0.05$). However, when the measurement days are concerned, significant difference was observed between the mean values of the 1st and 3rd days and the 7th day.

Hildrum *et al.* [31] worked on *Longissimus dorsi* muscle to investigate the effect of ES on chilling and freezing in terms of beef quality characteristics. With the treatment of 90 V and 15 Hz for 32 seconds, they observed that during agening, chilling and freezing are not effective. Polidori *et al.* [15], similarly to our work, measured shear force values on the 2nd and the 7th days, and reported that ES remarkably affected these values and improved tenderness. The shear force results showed that ES treated on *Longissimus dorsi* muscle at the 48th hour had a noteworthy effect, while the same effect was not observed in *Semitendinosus* muscle. Wiklund *et al.* [16] had findings very similar to each other in *Longissimus dorsi* and *Biceps femoris* muscles in terms of yield and composition, and they reached highly positive results in shear force values. Yanar and Yetim [10] reported that while Instron Warner-Bratzler Shear parameters, such as peak force, initial force, belonging to LD muscle, are highly affected by ES ($p<0.01$), *Semimembranosus* (SM) is not affected at all. Instron Compression Test result, thoughness and peak force 2 values obtained from LD were significantly affected ($p < 0.05$) by ES. On the other hand, it is observed that Instron Compression Test parameters of SM muscle were not affected by ES. Geesink *et al.* [7] electrically stimulated 80 sheep with 1130 V for 20 minutes after slaughter.

Table 2. Average and standard errors of the shear force values measured in muscles.

Treatment	Day 1	Day 3	Day 7
ES 30	13.25 ±0.857	10.92 ±0.664^{ab}	10.11 ±0.519^{ab}
ES100	11.93 ±0.857	9.33 ±0.664^{b}	8.92 ±0.519^{b}
Control	14.05 ±0.606	11.34 ±0.470^{a}	10.85 ±0.367^{a}
Average	13.08 ±0.452^{A}	10.53 ±0.350^{A}	9.96 ±0.273^{B}
p	NS	NS	*

^{a,b}: The difference between the mean values having a different letter at the same column is statistically important. [(*): $p < 0.05$] (NS) Statistically not significant ($p > 0.05$), Control: control group, ES Stimulation treatment A.B: The difference between the mean values having a different letter at the same row is statistically important.

Table 3. Average and standard errors of the color characteristics in muscles.

Treatment	Day 1			Day 3			Day 7		
	L	*a*	*b*	*L*	*a*	*b*	*L*	*a*	*b*
ES 30	34.30 ±2.183	13.40 ±0.676^{ab}	17.30 ±0.758^{ab}	35.20 ±1.661^{ab}	12.62 ±0.684^{ab}	17.80 ±0.894	36.40 ±1.397^{a}	11.90 ±0.817^{ab}	16.24 ±1.761
ES100	35.90 ±2.183	14.60 ±0.676^{a}	16.20 ±0.758^{b}	37.30 ±1.661^{a}	13.80 ±0.684^{a}	17.55 ±0.894	39.80 ±1.397^{a}	12.70 ±0.817^{a}	15.77 ±0.854
Control	33.46 ±1.544	12.80 ±0.478^{b}	19.10 ±0.536^{a}	32.66 ±1.175^{b}	11.90 ±0.484^{b}	18.70 ±0.632	32.45 ±0.988^{b}	10.50 ±0.578^{b}	16.81 ±7.703
Average	34.55 ±1.151 ^{B}	13.60 ±0.356 ^{A}	17.53 ±0.399	35.05 ±0.876 ^{B}	12.77 ±0.360 ^{A}	18.01 ±0.471	36.21 ±0.736 ^{A}	11.70 ±0.431 ^{B}	16.27 ±0.433
p	NS	NS	NS	NS	NS	NS	**	NS	NS

^{a,b}: The difference between the mean values having a different letter at the same column is statistically important. [(*): $p < 0.05$(**): $p < 0.01$]
(NS) Statistically not significant ($p > 0.05$), Control control group, ES Stimulation treatment
A.B: The difference between the mean values having a different letter at the same row is statistically important.

Led by the data they have obtained, in two days of post mortem, although the shear force values were positively affected, the analysis in the period of six weeks, showed no difference from the control groups. The results obtained by Zywica *et al.* [23] and Greathouse *et al.* [32] support our findings.

Crouse *et al.* [33] electrically stimulated only one side of the carcasses with 550V, 2-2.5 A and 60 Hz. The probes needed for the stimulation were applied between scapula, on thorasic vertebra and on the feet. The quality of meat and its conditions under high temperature were investigated for bulls. The carcass was chilled 48 hours after it was obtained, thus, the quality improvement of ES dropped unexpectedly. King *et al.* [34] planned the treatment in their study as one of the electrodes would be applied to the neck, and the other to the rail system. They observed that low voltage stimulation was not effective on meat color and tenderness improvement in goats. Nevertheless, high voltage treatment was observed to be effective on tenderness values on the 1-3 days of post mortem.

Color development was observed with the findings obtained from color measurement, while significantly different results shown in Table 3 for the 7th day were obtained ($P < 0.01$) only in *L**. Gadiyaram *et al.* [35], in their study with 20 castrated goat of two different breed, after the treatment of 580 V, measured the color values on the 24th hour, and different from our findings, they were not able to obtain significant relationship between ES and color. Crouse *et al.* [33] stimulated only one sides with 17 pulses at 550 V, 2-2.5 A and 60 Hz, and applied the probes to inter scapular thorasic vertebrae and to the feet. As a result, the stimulated sides had a brighter color and a fresh appearance; however, no difference between other quality parameters was observed. In terms of color parameters, Ferreira *et al.* [19] obtained significant differences in their study although they did not reach an intense correlation. Wiklund *et al.* [16] used 26 reindeer younger than 3 years. They completed stunning and slaughter processes in five minutes, and after eviscreation, they electrically stimulated them with 80 V for 20 seconds. Different from our findings, the measurements, which were carried out using a Hunter cromometer in order to obtain even color, did not reveal significant differences between the groups. Moreover, King *et al.* [34] reported that low voltage stimulation was not effective on meat color and tenderness of goats.

Results obtained from total mesophylic aerobic bacteria count values show that ES implementation has a microbiologically positive effect; however, in terms of their values, significant results ($p<0.01$) were observed only in *Longissimus* muscle. Biswas *et al.*[6] noticed that microbiological values were lower in electrically stimulated ones compared to the control group. This explains why shelf life of ES-treated meat is longer. Different from our findings, in the study of Kahraman [24] with 20 sheep stimulated with 50 and 100 V, statistically significant difference was not observed in total mesophylic aerobic bacteria.

Sensory panel tests in both the raw and cooked for the quality parameters improved in the ES groups. However, values obtained from raw samples scores had significant differences ($p<0.01$). Yanar and Yetim [10] investigated the effects of ES on shear force and sensory quality parameters of aged sheep carcasses. For this purpose, carcass halves of 14 sheep at the age of 3-5 were electrically stimulated with 350 V, and the effects of ES on sensory shear force parameters were evaluated. It was seen that ES remarkably improved ($p<0.01$) the panel tenderness point of *Longissimus dorsi* (LD) muscle. Although Greathouse *et al.* [32] pointed out that ES causes a high amount of loss while the meat is beeing cooked, they have not observed any difference between the treatment and the control groups in this respect. On the contrary, they have reported that ES-treated meat were more delightful and juicy.

Conclusions

Low voltage electrical stimulation applied to goat carcasses not only hastens agening by declining pH and causes a better meat color and brightness by enhancing shear force values, but also improves its tenderness. Therefore, increasing the commercial value of goat carcasses, it is concluded that electrical stimulation has a positive effect on meat industry.

Acknowledgements

This study is summarized Tuna Topcu's MA thesis. The authors would like to thank Dr. Enver Baris Bingol from Istanbul University Dept. of Food Hygiene and Technology.

References

[1]Strydom, P. E., Frylinck, L. and Smith, M. F. 2005. Should electrical stimulation be applied when cold shortening is not a risk? Meat Science **4**:733-742.

[2]Shin, H.-G., *et al*. 2007. Tenderization and fragmentation of myofibrillar proteins in bovine *longissimus dorsi* muscle using proteolytic extract from *Sarcodon aspratus*. Food Science and Technology doi:10.1016/j.lwt.2007; 08:19.

[3]Chen, Q., Guoqing, H., Yingchun, J. and Hui, N. 2006. Effects of elastase

from a *Bacillus* strain on the tenderization of beef meat. Food Chemistry **98**:624–629.

[4]Ferguson, D. M., Daly B. L., Gardner, G. E. and Tume, R. K. 2008. Effect of glycogen concentration and form on the response to electrical stimulation and rate of post-mortem glycolysis in ovine muscle. Meat Science **78**:202-210.

[5]Nazlı, B., Ergun, O., Cetin, O., Bingol, E. B. and Kahraman, T. 2008. Effects of high voltage electrical stimulation on meat quality of beef carcasses. 6th International Scientific Meeting, Abstract Book **79**:10-14.

[6]Biswas, S., Das A. K., Banerjee, R. and Sharma, N. 2007. Effect of electrical stimulation on quality of tenderstretched chevon sides. Meat Science **75**:332–336.

[7]Geesink, G. H., Mareko, M. H. D., Morton, J.D. and Bickerstaffe, R. 2001. Effects of stress and high voltage electrical stimulation on tenderness of lamb *M. Longissimus*. Meat Science **57**:265-271.

[8]Hwang, I. H., Devine, C. E. and Hopkins, D. L. 2003. The biochemical and physical effects of electrical stimulation on beef and sheep meat tenderness. Meat Science **65**:677-691.

[9]Lee, J. H., Kannan, G., Eega, K. R., Kouakou, B. and Getz, W. R. 2008. Nutritional and quality characteristics of meat from goats and lambs finished under identical dietary regime. Small Ruminant Research **74**:255–259.

[10]Yanar, M. and Yetim, H. 2003. The effects of electrical stimulation on the sensory and textural quality properties of mutton carcasses. Turk. J. Vet. Anim. Sci. **27**:433-438.

[11]Smith, G. C. 1985. Effects of electrical stimulation on meat quality, color, grade, heat ring and palatability. In Dutson, T. R. and Pearson, A. M. (eds). Advances in Meat Research. AVI Publishing Company, Westport, CT, pp. 121–158.

[12]Devine, C. E., Lowe T. E., Wells R. W., Edwards, N. J., Hocking Edwards J. E., Starbuck T. J. and Speck, P. A. 2006. Pre-slaughter stress arising from on-farm handling and its interactions with electrical stimulation on tenderness of lambs. Meat Science **73**:304-312.

[13]Kondos, A. C. and Taylor, D. G. 1987. Effect of electrical stimulation and temperature on biochemical changes in beef muscle. Meat Science **19**:207–216.

[14]Nour, A. Y. M., Gomide, L. A., Mills, E. W., Lemenager, R. P. and Judge, M. D. 1994. Influence of production and postmortem technologies on composition and palatability of USDA select grade beef. Journal of Animal Science **72**:1224–1231.

[15]Polidori, P., Lee, S., Kauffman, R. G. and Marsh, B. B. 1999. Low voltage electrical stimulation of lamb carcasses: effects on meat quality. Meat Science **53**:179-182.

[16]Wiklund, E., Finstad G., Johansson, L., Aguiar, G. and Bechtel, P.J. 2008. Carcass composition and yield of Alaskan reindeer (*Rangifer tarandus tarandus*) steers and effects of electrical stimulation applied during field slaughter on meat quality. Meat Science **78**:185–193.

[17]Yıldırım,Y. 1996. Et Endüstrisi. Kozan Ofset Mat. San.Tic.Ltd.Şti.Ankara, pp. 239-245.

[18]Hertog-Meischke, M. J. A., Smulders, F. J. M., Logtestijn, J. G. and Knapen, F. 1997. The effect of electrical stimulation on the water-holding capacity and protein denaturation of two bovine muscles. J. Anim. Sci. **75**:118–124.

[19]Ferreira, G. B. , Andrade, C. L., Costa, F., Freitas, M. Q., Silva, T. J. P. and Santos, I. F. 2006. Effects of transport time and rest period on the quality of electrically stimulated male cattle carcasses. Meat Science **74**:459–466.

[20]Harrigan, W. F. 1998. Laboratory Methods in Food Microbiology. Academic Press, London.

[21]Kerth, C. R., Cain, T. L., Jackson, S. P., Ramsey, C. B. and Miller, M. F. 1999. Electrical stimulation effects on tenderness of five muscles from Hampshire x Rambouillet crossbred lambs with the Callipyge phenotype. J. Anim. Sci. **77**:2951-2955.

[22]SPSS 9.01 for Windows 1998, SPSS Inc, Chiago, IL.

[23]Żywica, R. and Banach, J.K. 2007. Analysis of changes in electric current intensity during high voltage electrical stimulation in the aspect of predicting the pH value of beef. Journal of Food Engineering **81**:560-565.

[24]Kahraman, T. 2007. Küçükbaş Hayvan Karkaslarina Uygulanan Düşük Voltaj Elektrik Stimülasyonunun Et Kalitesi Üzerine Etkisi. I. U. Saglık Bilimleri Enstitusu, Doktora Tezi.

[25]Taylor, A. A., Nute, G. R. and Warkup, C. C. 1995. The effect of chilling, electrical stimulation and conditioning on pork eating quality. Meat Science **39**:339-347.

[26]Channon, H. A., Baud, S. R., Kerr, M. G. and Walker, P. J. 2003. Effect of low voltage electrical stimulation of pig carcasses and ageing on sensory attributes of fresh pork. Meat Science **65**:1315-1324.

[27]Channon, H. A.,Walker P. J., Kerr M. G. and Baud, S. R. 2003. Application of constant current, low voltage electrical stimulation systems to pig carcases and its effects on pork qualty. Meat Science **3**:1309-1313.

[28]Bond, J. J., Can, L. A. and Warner, R. D. 2004. The effect of exercise stres, adrenaline injection and electrical stimulation on changes in quality attributes and proteins in *Semimembranosus* muscle of lamb. Meat Science **3**:469-477.

[29]Li, C. B., Chen, Y. J., Xu, X. L., Huang, M., Hu, T. J. and Zhou, G. H. 2006. Effects of low-voltage electrical stimulation and rapid chilling on meat quality characteristics of Chinese Yellow crossbred bulls. Meat Science **1**:9-17.

[30]Rosenvold, K., North, M., Devine, C., Micklander, E., Hansen, P., Dobbie, P. and Wells, R. 2008. The protective effect of electrical stimulation and wrapping on beef tenderness science. Meat Science **2**:299-306.

[31]Hildrum, K. I., Solvang, M., Nilsen, B. N., Frøystein, T. and Berg J. 1999. Combined effects of chilling rate, low voltage electrical stimulation and freezing on sensory properties of bovine *M. longissimus dorsi*. Meat Science **52**:1-7.

[32]Greathouse, J. R., Hunt M. C., Dikeman, M. E., Corah, L. R., Kasmer, C. L. and Kropf, D. H. 1983. Ralgro-implanted bulls performance, carcass characteristics, longissimus palatability and carcass electrical stimulation. Journal of Animal Science **5**:355-363.

[33]Crouse, J. D., Seideman S. C. and Cross H. R. 1983. The effects of carcass electrical stimulation and cooler temperature on the quality and palatability of bull and steer beef. Journal of Animal Science **56**:81-90.

[34]King, D. A., Voges, K. L., Hale, D. S., Waldron, D. F., Taylor, C. A. and Savell, J.W. 2004. High voltage electrical stimulation enhances muscle tenderness, increases aging response, and improves muscle color from Cabrito carcasses. Meat Science **68**:529-535.

[35]Gadiyaram, K. M., Kannan, G., Pringle, T. D., Kouakou, B., McMillin, K. W. and Park, Y. W. Effects of post mortem carcass electrical stimulation on goat meat quality characteristics. Meat Science **78**:106-114.