EFFECT OF ELECTRICAL STIMULATION ON CHEVON QUALITY

By

MAJOR EMMANUEL MATHEW

THESIS

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Faculty of Veterinary and Animal Sciences
Kerala Agricultural University

Department of Veterinary Public Health
COLLEGE OF VETERINARY AND ANIMAL SCIENCES
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DECLARATION

I hereby declare that this thesis entitled "EFFECT OF ELECTRICAL STIMULATION ON CHRONAXIE" is a bonafide record of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Signature of the candidate

Name of the candidate: Major Immanuel Mathew

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16-10-1990.

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Certified that this thesis, entitled EFFECTS OF ELECTRICAL STIMULATION ON CHEVON QUALITY is a record of research work done independently by Major Emmanual Mathew under my guidance and supervision and that it has not previously formed the basis for the award of any degree, followship or associateship to him.

Name of the Guide : Dr. R. Padmanabha Iyer

(Chairman, Advisory Board)

Designation : Professor and Head, Department of Veterinary Public Health

Mannuthy,
16-10-1990.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Introduction

1. INTRODUCTION

India has the world's largest livestock population. But our meat production is only 0.865 million tonnes, of which goats contribute 32% and sheep 14% (FAO, 1979). The Indian Institute of Foreign Trade (IIFT, 1979) had estimated the potential of our meat production and predicted an export-potential of beef and mutton to the tune of 900 million U.S. Dollars, yearly. Unlike in most meat-producing countries, animals are not bred exclusively for meat purpose in India. Our present meat supplies are primarily derived from 'spent' animals (Padda et al., 1986). Meat from such animals is often tough and of inferior quality.

There is an overwhelmingly high consumer preference for fresh meat in India. Practically all meat is sold from retail butcher shops without exposure to any chilling process (Padda et al., 1986). We also lack sufficient infrastructural facilities for chilling and freezing of meat. Only a nominal 0.02% of the total meat produced is processed into meat products in India (IVRI, 1979), against nearly 80% in advanced countries. The customary practice of hot-boning and the prevailing high ambient temperature affect the meat quality.

"Meat quality" includes wholesomeness, nutrient content, palatability, attractiveness and the capacity of muscle to retain fluids during handling and processing. Palatability, or the eating quality of meat, which is important to the

consumer, depends to a considerable extent on tenderness, juiciness and flavour. The various factors influencing these quality traits have been studied extensively over the past few decades. Meat tenderness is known to be influenced by both pre-slaughter and post-slaughter factors. Animal-species breed, blood-line, nutritional status, sex and age at slaughter are the important pre-slaughter factors influencing tenderness. Handling, storage and cooling methods affect tenderness after slaughter of the animal. It is established that post-slaughter treatments can considerably influence the quality attributes.

In order to improve the quality of meat produced and to exploit our vast production potentials, it is essential to undertake some concerted efforts to modernise the production management and slaughter, storage and processing facilities. It will not only enhance the confidence of the importing countries but also avoid consignment rejections and huge economic losses.

Of the various methods of improving meat quality, electrical stimulation (ES) of carcasses is a relatively more recent advancement. Various workers have reported that ES improves meat tenderness in different species of animals. Further, this method is of greatest benefit for use on carcasses which would inherently produce less tender meat (Cross, 1979). Therefore, it is more suited for use in our meat industry.

Most of the works related to ES have been done on beef

and lamb carcasses. In India also, some preliminary studies in the field have been done on sheep carcasses (Attrey, 1980; Reddy, 1986 and Mahajan and Panda, 1989A). Though a high percentage of animals slaughtered here comprises of goats, no work seems to have been conducted in India to study the effect of ES on goat carcasses. Therefore, the present study was designed to examine the effects of carcass stimulation on chevon quality. Its effects on muscle pH, muscle glycogen content, sarcomere length, fibre diameter, water holding capacity and extract release volume were studied. Sensory evaluation of meat samples was also conducted to assess the response to ES on eating quality.

Review of Literature

2. REVIEW OF LITERATURE

2.1. History

Harsham and Deatherage (1951) were the first workers to employ electrical stimulation of freshly slaughtered beef carcasses as a means of accelerating the onset of rigor in musculature. They demonstrated that a brief period of ES helped to tenderise meat and suggested that this was due to enhancement of endogenous enzyme activity. In the same year, Renbschlor (1951) investigated the use of ES as an aid to improving tenderness in meat.

It was shown by Hallund and Bendall (1965) that an irreversible acceleration of glycolysis was induced by a 1-2 min ES of pre-rigor pork muscles. Bendall (1966) stated that ES of Large White Pork carcasses had a marked hastening effect on the rate of fall of pH, even when the muscles were curarised. Because of the risk of inducing PSE-like conditions in the carcasses, the results of the above works went unrecognised for some time.

However, during the early 1970s, a specific need arose in New-Zealand to overcome the toughening due to pre-rigor chilling and freezing of lamb carcasses. Carse (1973), Davey et al. (1976) and Chrystall and Hagyard (1976) exploited the accelerating effect of ES on rigor onset to enable rapid chilling or freezing of carcasses with the minimum delay after slaughter without the danger of cold-shortening and the resultant toughening. These works led to the wide-spread

adaptation of carcass-ES to New Zealand factory conditions.

American and British workers like Bendall et al. (1978), Dutson et al. (1977, 1980), Smith et al. (1977, 1979), Savell et al. (1978A), Bendall (1980), George et al. (1980) and Sonaiya et al. (1982) did extensive work on beef carcasses and concluded that ES accelerated postmortem pH decline, hastened rigor development and improved meat tenderness.

Cross (1979) and Seideman and Cross (1982) reviewed the research works in the field of carcass ES and summarised the beneficial effects of ES as under: it hastens pH decline, accelerates rigor onset, prevents cold shortening, improves certain palatability traits, especially tenderness and flavour, and improves lean colour and lean maturity. Martin et al. (1983) stated that ES reduced heat ring formation.

Subsequently, the method had been widely applied by several workers on different species of animals like rabbits - Kang et al. (1983) and Morgan and Kuypers (1985), Pork - Gigiel and James (1984), Ockerman and Kwiatc (1985) and Prabhakar et al. (1986), Sheep - Rashid et al. (1982 and 1983), Stolarz et al. (1984), Chrystall et al. (1984), Bouton et al. (1984), Newbold and Small (1985), Solomon et al. (1986), Reddy (1986) and Mahajan and Panda (1989A), and beef - Riley et al. (1983), Stiffler et al. (1984), Taylor and Cornell (1985), Solomon (1986A), Jones et al. (1986) and Takahashi et al. (1987).

At present with the commercial availability of stimulating

equipments, ES has emerged as a widely adopted technological advancement in meat industry in many developed countries (Savell, 1985).

2.2. Electrical Stimulation of Goat Carcesses

Savell et al. (1977) used a commercial, low voltage stunning device to electrically stimulated goat and lamb carcasses and reported that ES resulted in significant increase in tenderness, overall palatability and sarcomere length in stimulated carcasses when compared to non-stimulated controls. McKeith et al. (1979) stimulated goat carcasses using an electric stunner delivering 100 volts AC current at 60 cycles per second. The total duration of ES was 50 secs consisting of 25 impulses of one sec. each with one sec. pause between impulses. The study revealed that ES goat carcasses produced more tender Longissimus dorsi, Semimembranosus and Biceps femoris muscles when compared to controls. They further observed that ES of goats could be performed with beneficial & effects on tenderization at any stage during the slaughter-dressing sequence.

Smith et al. (1980) working at the Texas Agricultural Experiment Station, carried out ES of goat carcasses along with other species and concluded that ES increased tenderness, improved flavour, brightened muscle colour, caused faster "setting up", increased muscle firmness, reduced the need for aging to assure satisfactory palatability and improved retail cut appearance.

2.3. Factors Influencing Electrical Stimulation

2.3.1. Animal-related factors.

The pre-slaughter state of the animal influences the effects of ES. Smith et al. (1977), Cross (1979) and Savell et al. (1980) reported more beneficial effects of ES on animals that would inherently produce tougher meat.

Judge et al. (1980) observed that sensory-panel tenderness and Warner Bratzler Shear tests showed stimulation induced tenderization to a greater degree in animals fed no grain or grain for a short term than animals fed long term.

Chrystall and Devine (1985) stated that ES of animals stressed prior to slaughter brought forward rigor to such a degree that it developed close to or during the period of stimulation itself and induced toughness due to irreversible contraction of the muscles.

Vanderwert et al. (1986) reported that ES resulted in differential responses in different breeds and sexes of cattle.

2.3.2. Operational factors.

Different voltage levels ranging from 12.5 to over 3000 volts peak have been used by various workers for effective stimulation of carcasses; 50-3000 volts by Harsham and Deatherage (1951), 600-1600 volts by Bendall et al. (1978), 50-350 volts by Rashid et al. (1983), 12.5-110 volts by Newbold and Small (1985) and 45-145 volts by Solomon et al. (1986). Most recent

trends in application of ES use low voltages for safety and economic reasons - Stiffler et al. (1984).

Frequencies of current ranging from 0.5 Hz to 100 Hz have been used for carcass stimulation by various workers - Chrystall and Devine (1978), Ruderus (1980), Deatherage (1980), Marsh et al. (1981) and Takahashi et al. (1984 and 1987). In general, low frequencies caused rapid muscle glycolysis, yet produced no extensive tissue-rupture - Takahashi et al. (1984), and high frequencies resulted in tissue shattering and sarcomere stretching - Takahashi et al. (1987).

Use of alternating current or frequent reversal of polarity was found advantageous in avoiding electrode polarization and transformer core saturation. - Swatland (1977) and Chrystall and Devine (1978). Chrystall and Devine (1985) clarified that pulse shape did not greatly determine the extent to which rigor development was hastened.

The position of the electrode on the carcass should be such that it allows larger surface area in contact with the conducting elements of the carcass - Swatland (1980) and Voyle and Henrickson (1982). The use of various electrode combinations at different locations on the carcass has been reported - Powell et al. (1985) and Solomon (1986B). Effective stimulation using two metal probes, approx. 0.6 x 20 cm inserted one in the muscles of the leg and the other in the neck as electrodes, were reported by Savell et al. (1979), Berry and Stiffler (1981),

Griffin et al. (1981), Schroeder et al. (1982), Martin et al. (1983) and Solomon et al. (1986).

McKeith et al. (1979) and (1981) found that effective ES could be carried out at any stage during the slaughter-dressing sequence. Chrystall and Hagyard (1976) observed that the voltage requirement could be considerably reduced if sheep carcasses were defleeced before ES. Smith et al. (1979) reported that ES improved tenderness of calf loin steaks whether stimulated with hide on or after dehiding. Stiffler et al. (1984) stated that as low voltage stimulation (under 70 V) uses the intact central nervous system for current flow to the muscles, low voltage ES treatment should be done with hide on immediately after bleeding.

Carcasses could be effectively stimulated either intact, dressed or split as sides - Bendall et al. (1978), McKeith et al. (1981) and Smulders et al. (1986). McKeith et al. (1979) found that Longissimus dorsi (LD) muscles of goats stimulated after splitting the carcasses were more tender than carcasses that were stimulated immediately after exsanguination. Mahajan and Panda (1989A) stimulated primal cuts from sheep carcasses and reported beneficial quality changes.

Carse (1973) stimulated lamb carcasses for 30 min to achieve pH 6 in the musculature in 3 hours. Chrystall and Hagyard (1975) achieved most of the effects of ES in inducing early rigor in the first few minutes of stimulation. Chrystall (1978) and Hagyard et al. (1980) obtained pH 5.9 in one hour

by ES for 60 sec., when stimulated within 5 min. of slaughter. The same pH was obtained by stimulating for 90 sec. when the post-mortem delay in ES was 30 min. Shorthose et al. (1986) considered a duration of 90 sec. ES satisfactory for most beneficial effects. They observed that increasing the duration of ES to 180 sec. failed to counterbalance the decreased effectiveness of ES due to post-slaughter delay in stimulation.

2.4. Effects of Electrical Stimulation

2.4.1. pH.

The measurement of muscle pH gives an indirect indication of the postmortem biochemical activity in the muscle. The stage of glycolysis and rigor development could be assessed by measuring muscle pH. Therefore, various workers have studied the effect of ES of carcasses// on hastening rigor development by measuring the rate of fall in muscle pH - Chrystall and Hagyard (1976) and Chrystall and Devine (1978). The latter workers observed that the fall in pH in electrically stimulated beef Sternomandibularis (SM) muscle occurred in two stages: a fall during the stimulation period itself, designated as "delta pH", which was 100 to 150 times that of the normal nonstimulated rate; and a fall following the cessation of ES, the rate designated as dpH/dt, was about 1.5 to 2 times higher than the normal nonstimulated rate.

Savell et al. (1979) reported significant changes in pH values of muscles in ES sides when compared to control sides

in split carcasses. However, no significant differences in pH values in both the groups could be observed at 12th hour or 24th hour. Etherington (1984) stated that at the point of death of an animal, the muscle pH was near neutrality and with adequate glycogen reserves in the muscle, a limit pH of about 5.5 was reached 6-24 hours after death. Newbold and Small (1983) observed that ES of muscles, sides or carcasses soon after slaughter caused a rapid fall in pH during the stimulation period and a subsequent rate of fall in pH that was faster than in nonstimulated controls.

Smulders and Dikslenboom (1985) studied the effect of different voltage combinations used for ES, on the rate of fall in pH. They reported that the combined effect of high and low voltage stimulation resulted in a significantly faster pH fall than high voltage alone. Ledward et al. (1986) reported that the LD muscles from the ES carcasses had pH values below 6.0 at one hour postmortem.

Chrystal and Devine (1985) stated that the magnitude of 'delta-pH' largely determined the time delay before muscles lost their capacity to cold shorten. The time for muscles to reach pH 6.0 measured the combined effects of 'delta pH' and 'dpH/dt', and was a useful indicator to evaluate the effect of ES in inducing early rigor.

Hofmann (1988) discussed in detail the importance and various methods of measuring muscle pH.

Mahajan and Panda (1989A) reported that ES of mutton primal cuts resulted in a drop in pH to 5.8-6.0 when compared to 6.4-6.7 in control within 3 hours. They further observed a linear relation between the duration of ES and the rate of drop in pH.

The accelerating effect of ES on the rate of fall in pH have been reported by many workers including Bendall (1976), Bouton et al. (1978), Taylor et al. (1981), Dzolgic et al. (1982), Rashid et al. (1983), Crouse et al. (1983), Marsh (1983), Chrystall et al. (1984), Dikeman et al. (1985), Eikelenboom and Smulders (1986), Solomon (1986), Solomon et al. (1986), Shorthose et al. (1986) and Unruh et al. (1986).

2.4.2. Muscle glycogen content.

One of the objectives of ES of carcasses is to accelerate the rate of postmortem glycolysis in the muscle. The continuing biochemical activities in the muscle even after death of the animal result in accumulation of lactate ions due to breakdown of glycogen. The ultimate pH in muscle is inversely related to the accumulation of these ions. The accelerated rate of glycolytic changes in the muscle as a result of ES had been studied indirectly by pH measurements - Chrystall et al. (1984), Pearson and Dutson (1985) and Smulders (1987). Reports on measurement of muscle glycogen content to monitor the effect of ES on accelerating the rate of glycolysis are scanty.

Dreiling et al. (1987) had discussed the importance of

estimation of muscle glycogen and the factors affecting glycogen content in muscles.

2.4.3. Sarcomere length and fibre diameter.

Sarcomere length and fibre diameter give indication to the state of contraction of the muscles. Herring et al. (1965) demonstrated that when muscles shorten, there is a corresponding decrease in the length of the sarcomeres and an increase in fibre-diameter which are accompanied by a decrease in tenderness.

Smith et al. (1977) observed that ES was associated with longer sarcomeres in muscles only in three of six comparisons and therefore concluded that the benefits of ES are not related to cold shortening alone. Savell et al. (1977) reported significant increase in sarcomere length for loins in stimulated goat carcasses. But their further studies (1978 and 1979) did not reveal any significant differences in sarcomere length attributable to ES. Bouton et al. (1978) and George et al. (1980) found that ES resulted in longer sarcomeres.

Elgasim et al. (1981) reported that there was no significant differences in sarcomere lengths of ES and control meat conditioned at 2 or 16°C. Griffin et al. (1981) found no differences in sarcomere lengths from raw products due to ES. However, sarcomeres from cooked roasts from ES samples were longer than control indicating that ES might have prevented some shortening of muscle fibres during cooking. Salm et al.

(1983) found evidence in sarcomere length-data supporting the theory that ES prevented cold-shortening. Works on the effect of ES on fibre diameter are not seen reported.

2.4.4. Water holding capacity (WHC).

Seideman et al. (1979) stated that the increased rate of pH decline in ES muscles might result in decreased water holding capacity. George et al. (1980) reported that there were no significant differences in drip loss between control and ES muscles. Bendall (1980) concluded that in the case of beef and lamb carcasses "there need be no fear of significant increases in drip as a result of ES".

Hostetler et al. (1982) suggested that the changes brought out by ES led to more protein-binding sites in the muscles, thus leading to more binding of water. They observed significantly lower cooking loss of 1.5% for the ES samples as compared to controls. Johnson et al. (1982) found no differences in weight loss between wholesale cuts from ES and non-ES pork sides.

Many workers had reported that ES resulted in reduced WHC - Martin et al. (1983), Oreshkin et al. (1986), Buts et al. (1986), Unruh et al. (1986) and Mahajan and Panda (1989A).

Ostoja and Korzeniowski (1984) reported that ES (380 V, 30 Hz, 0.5 A, for 2 min) following 50 minutes of slaughter did not have much influence on the solubility of myofibrillar proteins in 3% NaCl solution or the water holding capacity.

Smith (1985) stated that eventhough the pre-rigor conditions associated with ES were conducive to major problems in WHC due to the sharp pH drop (while the muscle temperature was still high), the WHC of meat was not affected as feared.

2.4.5. Extract Release Volume (ERV).

Electrical stimulation accelerates the rate of fall in pH. At the lowered pH levels, the properties of muscle proteins are altered and their ability to bind water decreases. The reduced binding ability results in higher ERV (Cook, 1968). Mahajan and Panda (1989A) reported higher ERV in ES muscle samples. They further observed a linear relationship between the duration of ES and ERV.

2.4.6. Sensory properties.

Savell et al. (1977, 1978, 1979 and 1981) reported increased sensory panel ratings for tenderness, connective tissue amount, flavour and overall palatability attributable to ES. Flavour desirability was increased by 10.4% in ES samples and this was suggested to be due to production of chemical compounds responsible for the "aged meat flavour".

Salm et al. (1981) observed that ES did not affect taste panel juiciness scores and flavour intensity scores. Griffin et al. (1981) reported that ES resulted in longer sarcomeres but did not affect palatability traits. Vognarova and Hujnakova (1982) stated that ES had a favourable effect on the sensory properties, especially tenderness. Calkins et al. (1982)

attributed the differences in flavour between steaks from ES and control sides to differences in the concentration of creatine phosphate, adenine nucleotides and their derivatives.

Increased tenderness in stimulated bull meat was reported by Savell et al. (1982), Greathouse et al. (1983) and Riley et al. (1983). Ray et al. (1983) stated that ES resulted in higher sensory ratings for tenderness, connective tissue and flavour intensity scores.

Smith (1985) stated that sensory panel evaluations indicated that steaks or chops from ES sides were, on the average, 26, 3, 12 and 32% more tender than steaks or chops from counterpart untreated sides for beef, pork, lamb and goats, respectively. He further reported that sensory panel evaluations of beef steaks of ES and control sides revealed significant increases in flavour desirability scores.

Solomon et al. (1986) observed that ES had significant effect on panel tenderness scores and shear force values. No significant differences due to ES were detected for sensory connective tissue or flavour intensity scores.

Vanderwert et al. (1986) reported that ES resulted in improved muscle fibre tenderness and overall tenderness and reduced the detectable connective tissue.

Materials and Methods

3. MATERIALS AND METHODS

3.1. Electrical stimulation

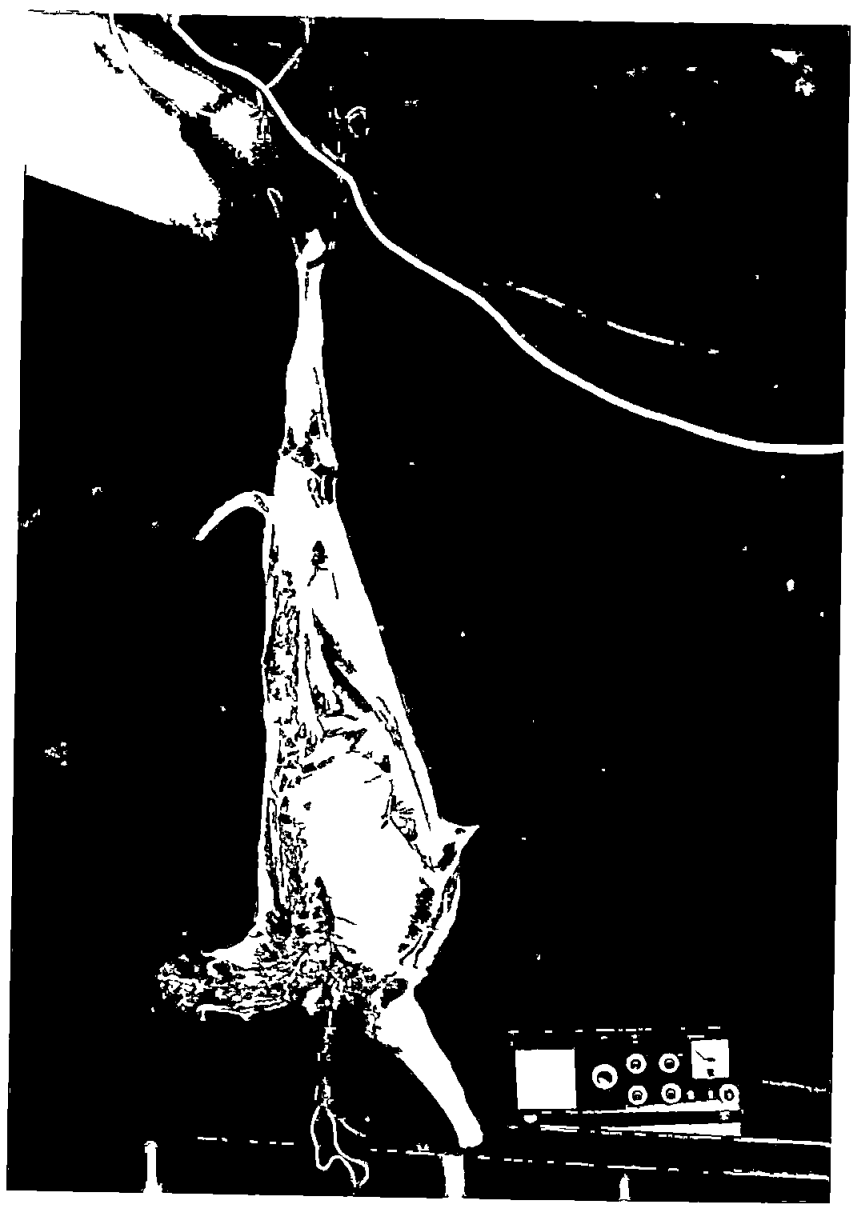
Ten adult female goats aged between 8 and 11 years (average age 8.5 years) reared on identical managemental conditions were selected for the experiment. The live weight ranged between 23.5 and 34.5 kg (Average 26.9 kg). The animals were lairaged for 24 hours, stunned using captive bolt pistol, exsanguinated, flayed and eviscerated. The carcasses were split longitudinally into two sides. One side from each carcass was randomly selected for electrical stimulation (ES), while the corresponding side served as the non-stimulated (NS) control.

The sides selected for ES were stimulated within 18-25 minutes of exsanguination, using a locally fabricated electric stimulator delivering pulsed alternating current (AC) at 150 volts, 50 Hz and 20 pulses per second (PPS). The total duration of stimulation for each side was 120 seconds with a stimulation cycle of two seconds ('on' and one second 'off'). The sides for ES were hung from an earthed rail using a stainless steel hook attached to the achilles tendon. A single copper electrode measuring 20 cm long and 0.6 cm in diameter was inserted into the muscles between scapula and thoracic vertebrae (McKeith et al., 1981) and it served as the live electrode (Plate I). The earthed rail served as the ground.

The Longissimus dorsi (LD) muscles from the control (NS) and experimental (ES) sides were excised and subjected to

Plate I. Split carcass before stimulation showing position of electrode

Plate I



comparative studies to assess the effect of ES on meat quality. The parameters studied were muscle pH, glycogen content, water holding capacity, extract release volume, sarcomere length and fibre diameter. Sensory evaluation was conducted at 24 hours post-ES, to assess effect on eating quality.

From the control side, the LD muscle was excised immediately after splitting of the carcasses. The LD muscle from the ES sides were removed immediately after completion of stimulation. Each excised muscle was divided into two portions. One portion was packed in polythene and stored at ambient temperature upto 12 hours and then preserved in the refrigerator (6-9°C) upto 24th hour for sensory evaluation. The other portion was packed in polythene and chilled (6-9°C) after 1 hr upto 24th hour. For comparative observations, samples from the corresponding sites on the muscles were drawn at specified intervals.

3.2. Estimation of pH

pH was estimated on a homogenate of one g of muscle in 10 ml of 0.005 M sodium iodoacetate (Moeller *et al.*, 1977), using a combined electrode, digital pH-meter. Longissimus dorsi muscle samples from both NS and ES sides stored at ambient temperature were drawn at 0 hr, 1 hr, 2 hr, 3 hr, 4 hr, 8 hr and 12 hr for pH estimation. From the refrigerated muscles, samples were taken at 4 hr, 8 hr, 12 hr and 24 hr.

3.3. Estimation of muscle glycogen

The glycogen content in the LD muscle was estimated by the method of Seifter et al. (1950) (Appendix A). From both NS and PS muscles stored at ambient temperature samples were drawn at 0 hr, 2 hr, 4 hr and 8 hr. From the refrigerated muscles, samples were taken at 4 hr and 8 hr for glycogen estimation. In each experiment, a total of 12 samples were analysed.

3.4. Estimation of water holding capacity (WHC)

WHC was estimated by the filter-paper-press method described by Wierbicki and Deatherage (1958). Samples from muscles stored at ambient temperature were drawn at 0 hr, 4 hr and 12 hr and from the refrigerated muscles at 4 hr, 12 hr, and 24 hr. Measurements of the 'meat film area' and 'total fluid area' were done using a polar planimeter. The result was expressed as a ratio of meat film area and total fluid area - Haufmann et al. (1962).

3.5. Estimation of Extract Release Volume (ERV)

ERV was estimated by the method of Pearson (1976). 15 g of minced meat sample was mixed with 60 ml of ERV reagent (Appendix B) and blended for one minute in an electrically operated blender. The homogenate was poured into a folded filter paper (Whatman No.1, 18.5 cm diameter) and the volume collected in 15 minutes was measured. From the muscles stored at ambient temperature, samples were drawn at 0 hr, 4 hr and

12 hr and from the refrigerated muscles at 4 hr, 12 hr and 24 hr for estimation of ERV.

3.6. Fibre diameter and sarcomere length

Fibre diameter and sarcomere length were measured by the methods of Khan et al. (1981) and Jeremiah et al. (1985) respectively. A four-gram sample of the LD muscle was scissor-minced into 20 ml of 0.25 M sucrose solution and homogenised for 5 sec. at 2-5°C. One drop of the resultant slurry was then transferred to a microscope slide and covered with a cover-slip. The length of 10 sarcomeres each from 25 fibre fragments was measured on a previously calibrated phase-contrast microscope under 1000 x magnification. The calibration was done using stage and ocular micrometers. The diameter of 25 muscle fibres were measured taking the average measurements at the centre and ends of each fibre. Samples for measurements in respect of muscles stored at ambient temperature were drawn at 0 hr, and 12 hr and for the refrigerated samples at 12 hr and 24 hr.

3.7. Sensory Evaluation

Sensory evaluation of the LD muscle samples from the NS and ES sides was conducted by a five member, semi-trained taste panel. The evaluation was done on a 9 point hedonic scale for tenderness, juiciness, flavour, sensory connective tissue and overall acceptability (score-card, Appendix C).

Samples for sensory evaluation were drawn as under. For

LD muscles stored at ambient temperature, the samples were maintained at ambient temperature upto 12 hrs and then preserved in a refrigerator (6-9°C) upto hr 24 for sensory evaluation. The muscles refrigerated after 1 hr of DS remained in the refrigerator upto hr 24 and then used for sensory evaluation.

The samples were cut to uniform size of approx 8 x $1\frac{1}{2}$ x $1\frac{1}{2}$ cm and packed in previously labelled polypropylene bags. For cooking, the bags were immersed in a boiling water bath for 40 minutes. The cooked meat samples were cut into 1 cm cubes and served to the members of the taste-panel for evaluation.

3.8. Meteorological observations

The ambient temperature (maximum and minimum) during the period of the experiment was obtained from the Agro-Met Station, KAU, Vellanikkara.

3.9. Statistical Analysis

The data was analysed by using Paired T-Test, Chi square test and calculation of correlation coefficient as explained by Snedecor and Cochran (1967) and the results had been interpreted.

Results

4. RESULTS

4.1. General observations

The ambient temperature recorded during the period of the experiment ranged between maximum 32.2 to 36.6°C and minimum 22.5 to 26.5°C.

The goat carcass sides responded to electrical stimulation by visible flexion of the forelimb, raising of the neck region due to vigorous bending laterally of the whole thoracic and cervical region (Plate II) and contraction of the muscles of the neck, trunk and thigh regions. These reactions were more intense during the initial 60 seconds of stimulation. Towards the end of the 120 sec stimulation period, the intensity of the visible movements was reduced considerably (Plate III).

Measurements of the physico-chemical changes in the LD muscles of the NS and ES sides at various time intervals post-ES, gave the following results.

4.2. Effect of ES on pH in LD muscles

The mean pH values of LD muscles at various time intervals after storage at ambient temperature are given in Table 1A.

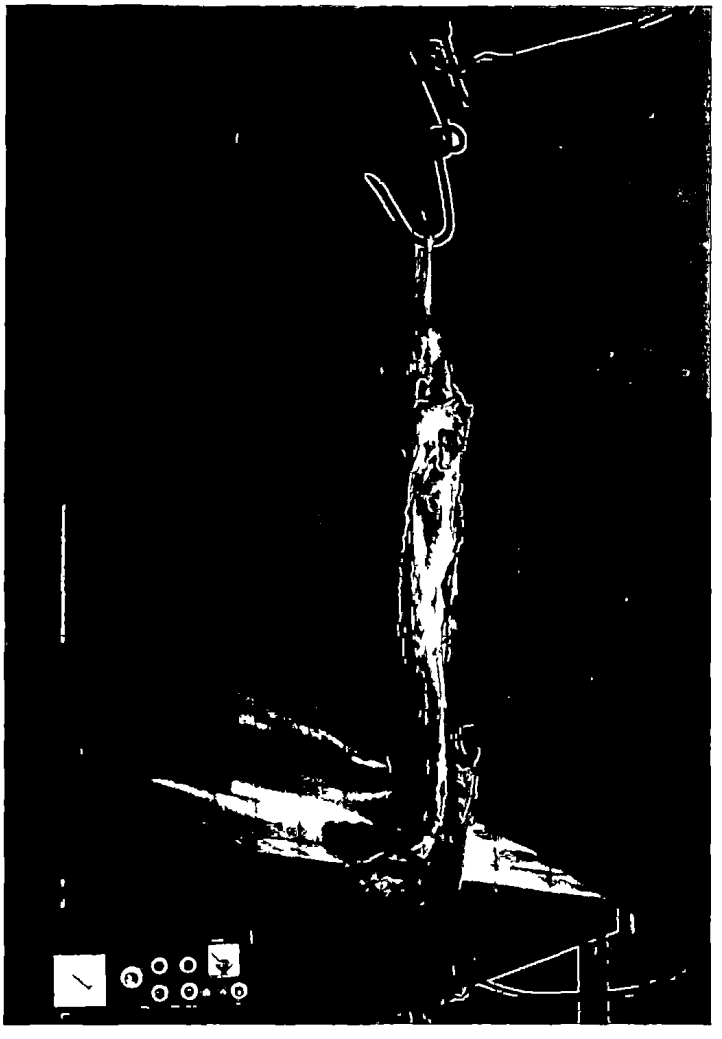
The mean initial pH in LD muscles of the carcasses studied was 6.453 ± 0.079. Electrical stimulation for 2 minutes resulted in a fall in pH to 6.028 ± 0.063. The pH values in the ES muscles stored at ambient temperature had fallen below 6.0 within one hour of ES, but in the NS muscles it took

Plate II. Carcass side during initial stage of stimulation showing maximum bending of the neck and flexion of forelimb

Plate II

Plate III. Carcass side during later half of stimulation showing reduced intensity of bending of neck and flexion of forelimb.

Plate III



nearly 4 hours for the pH to fall below 6.0. At four hours post-ES, the pH in ES muscles were significantly lower than that in the NS muscles. The ES muscles showed a pH of 5.652 ± 0.042 compared to 5.932 ± 0.055 in the NS muscles. After 8 and 12 hours of storage at ambient temperature there were no significant differences between the mean pH values for NS and ES muscles. At 8 hr, the pH in NS muscles was 5.76 ± 0.064, and in ES muscle 5.674 ± 0.031. The pH in NS muscle was 5.739 ± 0.055 compared to 5.729 ± 0.026 in the ES muscles at 12 hours.

Table 1B shows the mean pH values at various time intervals, in LD muscles stored at refrigeration temperature. At 4 hours post-ES (3 hours of refrigeration), the pH value in ES muscles was significantly lower than that in NS muscles. The former measured 5.781 ± 0.055 and the latter 6.099 ± 0.083. There were no significant differences between the mean pH of ES muscles and NS muscles at 8, 12 and 24 hours of refrigeration.

Fig.1A graphically represents the effect of ES on pH of LD muscles stored at ambient temperature. In the NS muscles, the pH showed a steady fall upto 8 hours. Between 8 and 12 hours, the pH continued to fall, though at a slower rate. In the ES muscles, the fall in pH was sharp during the period of stimulation, and showed a steady fall upto 4 hours. Between 4 and 8 hours the pH remained almost stationary and after 8 hours there was a slight increase in the pH upto 12 hours.

The effect of ES on pH of LD muscles which were refrigerated upto 24 hours after ES is shown in Fig. 1B. In the

Fig.1A. Changes in pH observed in stimulated and nonstimulated muscles, stored at ambient temperature

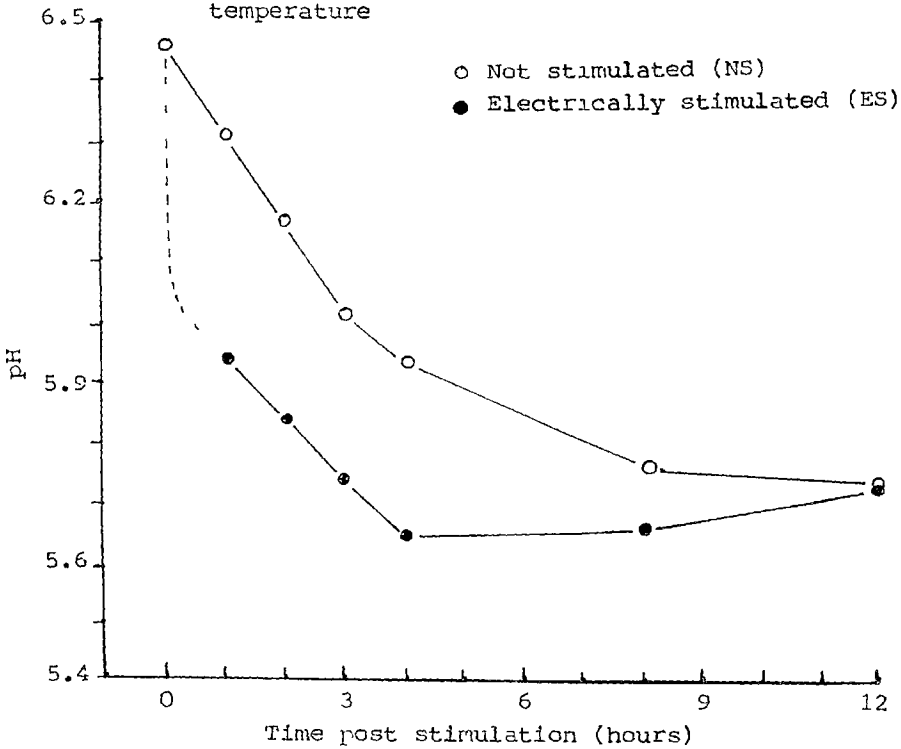
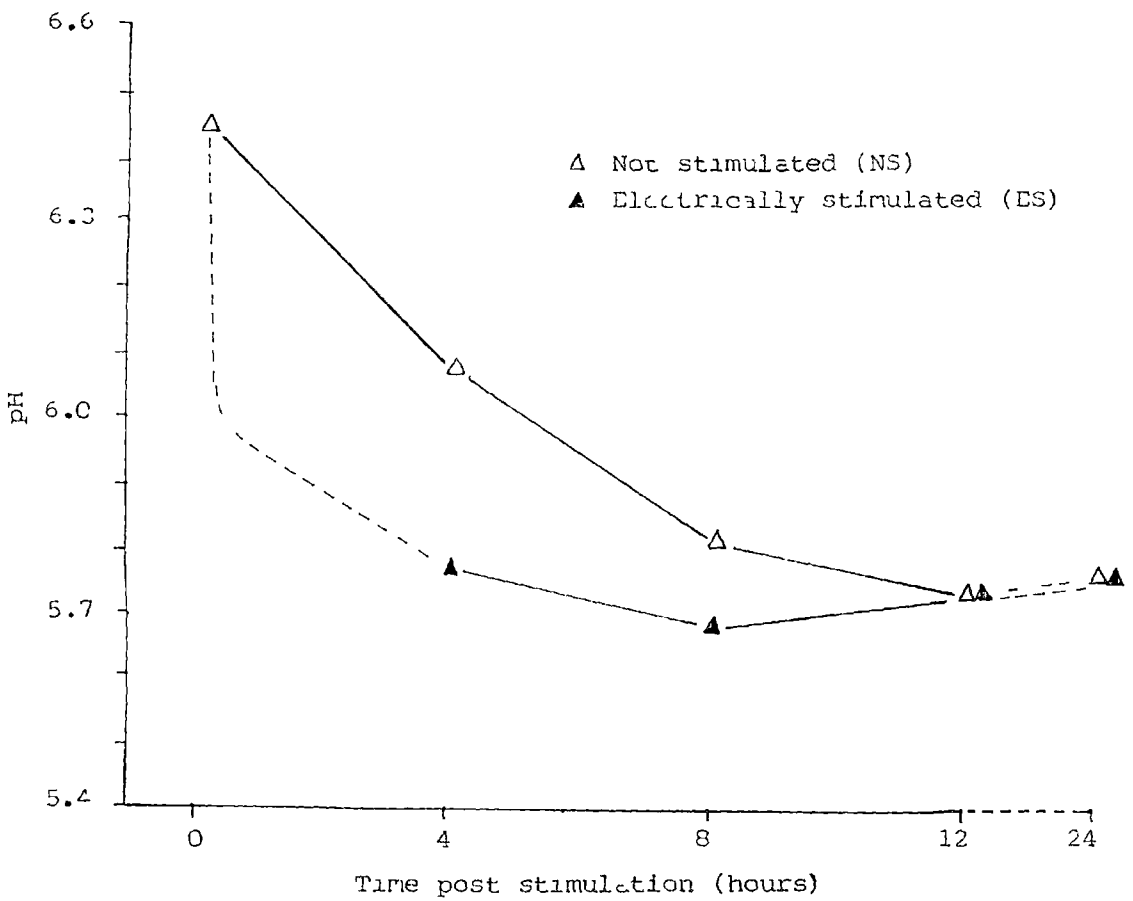


Fig.1B. Changes in pH observed in stimulated and nonstimulated muscles, stored under refrigeration



refrigerated NS muscles, the pH fell steadily during the first 4 hours. Between 4 and 12 hours the fall in pH was at a slower rate.

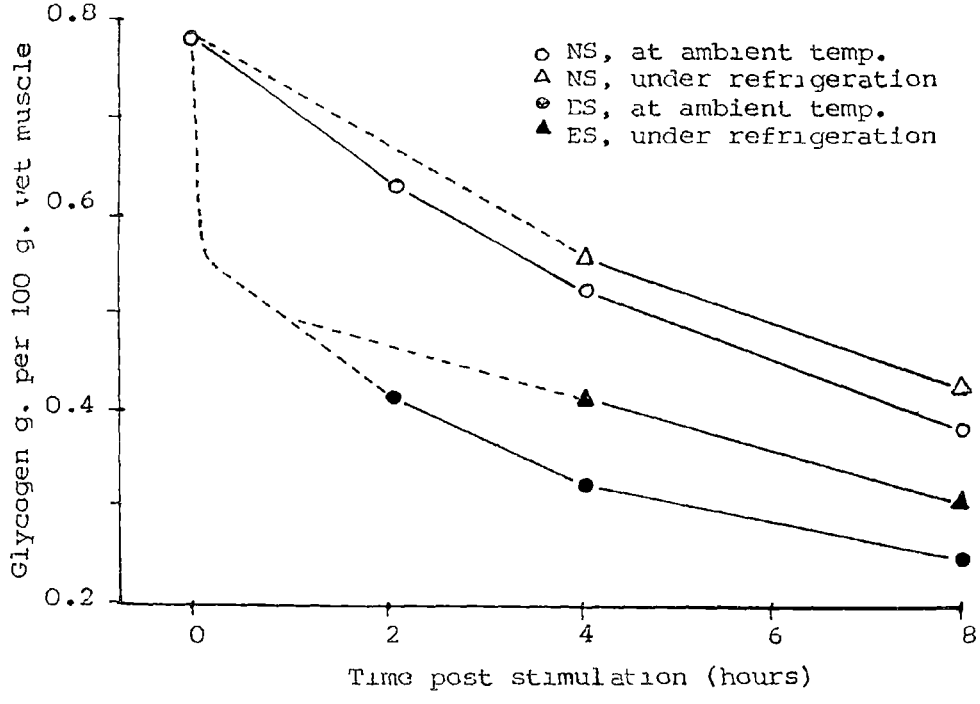
In the refrigerated ES muscles, the fall in pH during the initial 4 hours after ES was slower than in NS muscles. Between 4 and 8 hours the fall in pH in ES muscles followed a similar trend as in NS muscles. But after 8 hours the pH in ES muscles showed a slight increase upto 24 hours.

4.3. Glycogen content

The initial glycogen content in LD muscles of the goat carcasses studied was 0.738 ± 0.055 gram per 100 g wet meat. After electrical stimulation for 2 minutes duration, the mean glycogen content dropped to 0.553 ± 0.046 gram %. The change in glycogen content in LD muscles stored at ambient temperature is given in Table 2A. Both in NS and ES muscles, the glycogen content came down progressively with advancing time. The values for ES muscles were significantly lower than that for NS muscles at any given time studied (upto 8 hours post-ES). At the end of 8 hours post-ES, the values were 0.396 ± 0.026 and 0.250 ± 0.018 for NS and ES muscles respectively.

Table 2B shows the glycogen content (gram %) in LD muscles stored at refrigeration temperature. At 4 hours post-ES (3 hours refrigeration), the NS muscle had a glycogen content of 0.558 ± 0.049 which was significantly higher than the value for ES muscles (0.419 ± 0.039 gram %). Similarly at 8 hours

Fig.2. Changes in glycogen content in NS and ES muscles stored at ambient temperature and under refrigeration



post-ES, the glycogen content of NS muscles (0.421 ± 0.036 gram % was significantly higher than the value for ES muscles (0.314 ± 0.027 gram %).

Fig. 2 graphically represents the effect of ES on glycogen content in LD muscle under two storage conditions. In the NS muscles, the glycogen content dropped from 0.788 ± 0.055 g % to 0.396 ± 0.026 g % at ambient temperature and to 0.421 ± 0.036 g % at refrigeration temperature. The fall in glycogen content in NS muscle followed an almost uniform pattern, upto 8 hours. In the ES muscles, the glycogen content dropped sharply during the period of stimulation and thereafter followed a similar pattern as in NS muscles upto 8 hours. In both NS and ES muscles, the glycogen content tended to record lower values when stored at ambient temperature when compared to storage at refrigeration temperature.

4.4. Sarcomere length (SL)

The results of measurement of sarcomere lengths of LD muscle from NS and ES sides stored at ambient temperature and at refrigeration temperature are given in tables 3A and 3B.

The LD muscle had a mean initial sarcomere length of 1.411 ± 0.051 um. After stimulation the SL measured 1.525 ± 0.039 um which was not significantly different from the initial value. After 12 hours storage at ambient temperature the sarcomere length in ES muscles was 1.617 ± 0.048 um which was significantly higher than the SL of NS muscles, 1.393 ± 0.048 um (Table 3A).

At 12 hours post-ES, the LD muscle from ES sides stored at refrigeration temperature (Table 3B) had a SL of 1.524 ± 0.04 um which was significantly higher than the values for the corresponding NS muscles (1.280 ± 0.052 um). The ES muscle had a sarcomere length of 1.73 ± 0.041 um at 24 hours post-ES compared to 1.368 ± 0.055 um in the corresponding NS muscles. These values were significantly different.

4.5. Fibre diameter (FD)

Tables 4A and 4B shows the results of measurement of the fibre diameter in LD muscles from NS and ES samples stored at ambient temperature and refrigeration temperature.

The mean initial fibre diameter in LD muscle measured just prior to ES was 63.46 ± 2.78 um. After two minutes stimulation the fibre diameter was 63.20 ± 2.06 um which did not differ significantly from the initial value. After storage at ambient temperature for 12 hours the NS muscle had a fibre diameter of 68.16 ± 3.32 um and the ES muscle 62.94 ± 2.93 um. These values did not differ significantly.

In the refrigerated samples (Table 4B), the fibre diameter of NS muscles after 12 hours of refrigeration was 71.29 ± 2.95 um. The corresponding value for ES muscle was 64.11 ± 2.13 um and had no significant difference from the value for NS muscles. After 24 hours of refrigeration, the values for NS and ES muscles were 66.42 ± 2.58 um and 62.35 ± 2.01 um respectively and these values had no significant difference.

4.6. Water Holding Capacity

The results of estimation of WHC in LD muscles from NS and ES sides stored at ambient temperature and under refrigeration are given in Tables 5A and 5B.

The LD muscles had a mean initial WHC of 0.37 ± 0.03. After 2 minutes stimulation, the WHC measured 0.33 ± 0.03, which was not significantly different from the initial value. In the LD muscles stored at ambient temperature, the NS and ES muscles had WHC values of 0.37 ± 0.03 and 0.31 ± 0.03 respectively at 4 hours post-ES (Table 5A). These values were not significantly different. After storage for 12 hours at ambient temperature, the WHC in NS and ES muscles were 0.31 ± 0.03 and 0.27 ± 0.02 respectively and these values had no significant differences.

In the refrigerated samples, the NS muscle had a WHC of 0.39 ± 0.04 at 4 hours compared to 0.35 ± 0.03 in the ES muscles. The values of WHC at 12 hours were 0.32 ± 0.02 and 0.28 ± 0.02 for NS and ES muscles respectively. The WHC in NS and ES muscles were not significantly different at 4 hours and 12 hours post-ES (Table 5B). The WHC in NS muscle at 24 hours post-ES was 0.30 ± 0.02 which was significantly higher than the values for the corresponding ES muscles (0.24 ± 0.12).

4.7. Extract Release Volume

The results of ERV estimation in the LD muscles of the NS and ES sides are given in Tables 6A and 6B.

The mean initial values of DRV in the LD muscles of the carcasses studied was 33.4 ± 0.86 ml. After 2 minutes of ES, the DRV increased to 37.4 ± 0.69 ml which was significantly higher than the initial value. At 12 hours post-ES, the NS muscles stored at ambient temperature had an DRV of 30.9 ± 1.16 m which was significantly lower than the value for the corresponding ES muscles (34.4 ± 0.93 ml).

In the refrigerated samples, the NS muscle had an DRV of 28.6 ± 1.18 ml at 12 hours post-ES compared to 30.0 ± 1.0 ml for the corresponding ES muscles (Table 6B). These values did not differ significantly. After 24 hours of refrigeration, the NS and ES muscles had DRV values of 29.2 ± 1.41 ml and 32.4 ± 1.14 ml respectively. The difference between the values was not significant.

4.8. Sensory evaluation

The results of sensory evaluation of LD muscle samples from NS and ES sides are given in Tables 7A and 7B.

On sensory evaluation of the samples stored at ambient temperature (Table 7A), the ES muscles had a tenderness rating of 5.97 ± 0.22 on a 9 point hedonic scale compared to 4.93 ± 0.15 in the corresponding NS muscles. This difference was statistically significant. The flavour rating of NS and ES muscles were 4.87 ± 0.09 and 5.02 ± 0.09 respectively and they did not differ significantly. The NS muscle had a juiciness score of 4.78 ± 0.13 which was not significantly different from the score for ES muscles (5.1 ± 0.14). The connective

tissue rating for NS muscle was 5.04 ± 0.16 and it was significantly lower than the rating for DS muscles (5.88 ± 0.14). There was significant difference between the scores for overall acceptability in respect of NS muscle (5.12 ± 0.17) and DS muscle (6.06 ± 0.2).

The samples stored at refrigeration temperature also showed a similar pattern (Table 7B) of difference between NS and DS muscles. The DS muscles had significantly higher scores for tenderness, sensory connective tissue and overall acceptability than NS muscles. The DS and NS muscles did not differ significantly in their scores for flavour and juiciness.

4.9. Correlation studies

Chi square test performed to find out the relation between the rate of fall in pH and the rate of fall in glycogen content in LD muscles indicated that these two rates were independent of each other as Chi square was not significant at 5% level ($x_2^2 = 0.4847$).

Correlation coefficients of all important combinations of the parameters studied were worked out. The results were interpretted and the following correlations observed.

Sarcomere length and fibre diameter of LD muscles from the NS sides stored at ambient temperature had a correlation of -0.702 ($P < 0.05$) and in the refrigerated NS muscle the correlation was -0.643 ($P < 0.05$). In the corresponding DS muscles there was no significant correlation between these two parameters.

Sarcomere length did not show any correlation with any of the sensory qualities in all groups of muscles studied.

Tenderness in LD muscles from NS sides stored at ambient temperature had correlation with sensory connective tissue rating (+0.679, $P < 0.05$), and overall acceptability (+0.915, $P < 0.01$) while the corresponding ES muscles showed correlation of tenderness with sensory connective tissue rating (+0.831, $P < 0.01$), overall acceptability (+0.982, $P < 0.01$) and flavour (+0.744, $P < 0.01$).

In the refrigerated NS muscles, tenderness was found to be correlated with overall acceptability (+0.788, $P < 0.01$) and juiciness (+0.695, $P < 0.05$) but not with sensory connective tissue rating (+0.530, $P > 0.05$). But in the corresponding ES muscles, tenderness had correlation with overall acceptability (+0.920, $P < 0.01$) and sensory connective tissue rating (+0.665, $P < 0.05$) but not with juiciness (+0.572, $P > 0.05$).

Overall acceptability in NS muscles stored at ambient temperature was correlated with tenderness (+0.915, $P < 0.01$), sensory connective tissue rating (+0.843, $P < 0.01$) and flavour (+0.653, $P < 0.05$). Similarly, in the corresponding ES muscles, overall acceptability had correlation with tenderness (+0.982, $P < 0.01$), sensory connective tissue rating (+0.857, $P < 0.01$) and flavour (+0.801, $P < 0.01$).

In the refrigerated NS muscles, overall acceptability was correlated with tenderness (+0.788, $P < 0.01$), sensory

connective tissue rating (+0.766, $P < 0.01$), flavour (+0.712, $P < 0.05$) and juiciness (+0.665, $P < 0.05$). But in the corresponding ES muscles, overall acceptability had correlation with tenderness (+0.920, $P < 0.01$) and sensory connective tissue (+0.804, $P < 0.01$) but not with flavour (+0.565, $P > 0.05$) and juiciness (+0.565, $P > 0.05$).

Sensory connective tissue rating showed correlation with juiciness in all groups of muscles. The values were (+0.732, $P < 0.05$), (+0.725, $P < 0.05$), (+0.759, $P < 0.05$) and (+0.751, $P < 0.05$) for NS and ES muscles stored at ambient temperature and NS and ES muscles refrigerated, respectively.

Tables

Table 1A. pH changes observed in stimulated and non-stimulated goat carcasses, stored at ambient temperature.

Time hours	pH NS	SE	pH ES	SE	Test of significance at 5 % level
0	6.453[a]	0.079	6.028[b]	0.063	Significant
1	6.305	0.093	5.940	0.067	Significant
2	6.176	0.064	5.845	0.062	Significant
3	6.052	0.062	5.742	0.048	Significant
4	5.932	0.055	5.652	0.042	Significant
8	5.760	0.064	5.674	0.031	Not significant
12	5.739	0.055	5.729	0.026	Not significant

Treatments: NS = Not stimulated
ES = Electrically stimulated

a = reading immediately before ES

b = reading immediately after ES

All values are means ± S.E. of 10 observations

Table 1B. pH changes observed in stimulated and non-stimulated goat carcasses, stored under refrigeration

Time hours	pH NS	SE	pH ES	SE	Test of significance at 5% level
0	6.453[a]	0.079	6.028[b]	0.063	Significant
4	6.099	0.083	5.781	0.055	Significant
8	5.812	0.057	5.695	0.037	Not significant
12	5.744	0.052	5.744	0.045	Not significant
24	5.770	0.057	5.771	0.057	Not significant

Treatments: NS = Not stimulated
ES = Electrically stimulated
a = reading immediately before stimulation
b = reading immediately after stimulation
All values are Mean ± SE of 10 observations

Table 2A. Changes in glycogen content due to electrical stimulation in goat muscles during post-ES storage at ambient temperature

Time hours	Glycogen (gram %) NS	SE	Glycogen (gram %) ES	SE	Test of significance at 5% level
0	0.788[a]	0.055	0.553[b]	0.046	Significant
2	0.629	0.053	0.419	0.042	Significant
4	0.521	0.040	0.343	0.027	Significant
8	0.396	0.026	0.250	0.018	Significant

Treatments: NS = Not stimulated
ES = Electrically stimulated
a = Value immediately before ES
b = Value immediately after ES
All values are mean ± SE of 10 observations

Table 2B. Changes in glycogen content due to electrical stimulation, in goat muscles, during post-ES storage under refrigeration

Time of refrigeration (hours)	Mean glycogen (gram %) NS	SE	Mean glycogen (gram %) ES	SE	Test of significance at 5% level
0	0.788[a]	0.055	0.553[b]	0.046	Significant
4	0.558	0.049	0.419	0.039	Significant
8	0.421	0.036	0.314	0.027	Significant

Treatments: NS = Not stimulated
ES = Electrically stimulated
a = Value immediately before ES
b = Value immediately after ES
All values are Mean ± SE of 10 observations

Table 3A. Influence on sarcomere lengths due to electrical stimulation of goat muscles, on storage at ambient temperature

Time of storage (hours)	Sarcomere length (um) NS	SE	Sarcomere length (um) ES	SE	Test of significance at 5% level
0	1.411[a]	0.051	1.525	0.039	Not significant
12	1.393	0.048	1.617	0.048	Significant

Treatments : NS = Not stimulated
ES = Electrically stimulated

a = Values immediately before ES

b = Values immediately after ES

All values are Mean ± SE of ten observations

Table 3B. Influence on sarcomere length due to electrical stimulation of goat muscles, on storage under refrigeration

Time of refrigeration (hours)	Sarcomere length (um) NS	SE	Sarcomere length (um) ES	SE	Test of significance at 5% level
0	1.411[a]	0.051	1.525[b]	0.039	Not significant
12	1.280	0.052	1.524	0.040	Significant
24	1.368	0.055	1.730	0.041	Significant

Treatments: NS = Not stimulated
ES = Electrically stimulated

a = Values immediately before ES

b = Values immediately after ES

All values are mean $\pm$ SE of ten observations

Table 4A. Influence on fibre diameter due to electrical stimulation of goat muscles, on storage at ambient temperature

Time of storage (hours)	Fibre diameter (um) NS	SE	Fibre diameter (um) ES	SE	Test of significance at 5% level
0	63.46[a]	2.78	63.20[b]	2.06	Not significant
12	68.16	3.32	62.94	2.93	Not significant

Treatments: NS = Not stimulated
ES = Electrically stimulated

a = Value immediately before ES

b = Value immediately after ES

All values are mean ± SE of 10 observations

Table 4B. Influence on fibre diameter due to ES of goat muscles, on storage under refrigeration

Time of refrigeration (hours)	Fibre diameter (um) NS	SE	Fibre diameter (um) ES	SE	Test of significance at 5% level
0	63.46[a]	2.78	63.20[b]	2.06	Not significant
12	71.29	2.95	64.11	2.13	Not significant
24	66.42	2.58	62.35	2.01	Not significant

Treatments: NS = Not stimulated
ES = Electrically stimulated

a = Value immediately before ES

b = Value immediately after ES

All values are mean ± SE of 10 observations

Table 5A. Influence on water holding capacity, due to ES of goat muscles, on storage at ambient temperature

Time of storage (hours)	WHC NS	SE	WHC ES	SE	Test of significance at 5% level
0	0.37[a]	0.03	0.33[b]	0.03	Not significant
4	0.37	0.03	0.31	0.03	Not significant
12	0.31	0.03	0.27	0.02	Not significant

Treatments: NS = Not stimulated
ES = Electrically stimulated
a = Values immediately before ES
b = Values immediately after ES
All values are mean ± SE of ten observations

Table 5B. Influence on water holding capacity due to ES of goat muscles, on storage under refrigeration

Time of refrigeration (hours)	WHC NS	SE	WHC ES	SE	Test of significance at 5% level
0	0.37[a]	0.03	0.33[b]	0.03	Not significant
4	0.39	0.04	0.35	0.03	Not significant
12	0.32	0.02	0.28	0.02	Not significant
24	0.30	0.02	0.24	0.12	Significant

Treatments: NS = Not stimulated
ES = Electrically stimulated
a = Values immediately before ES
b = Values immediately after ES
All values are mean ± SE of ten observations

Table 6A. Influence on extract release volume due to ES of goat muscles, on storage at ambient temperature

Time of storage (hours)	ERV (ml) NS	SE	DRV (ml) ES	SE	Test of significance at 5% level
0	33.4[a]	0.86	37.4[b]	0.69	Significant
12	30.9	1.16	34.4	0.93	Significant

Treatments: NS = Not stimulated
ES = Electrically stimulated

a = Values immediately before ES

b = Values immediately after ES

All values are Mean ± SE of ten observations

Table 6B. Influence on extract release volume due to ES of goat muscles, on storage under refrigeration

Time of refrigeration (hours)	ERV (ml) NS	SE	ERV (ml) ES	SE	Test of significance at 5% level
0	33.4[a]	0.86	37.4[b]	0.69	Significant
12	28.6	1.18	30.0	1.00	Not significant
24	29.2	1.41	32.4	1.14	Not significant

Treatments: NS = Not stimulated
ES = Electrically stimulated

a = Values immediately before ES

b = Values immediately after ES

All the values are mean ± SE of 10 observations

Table 7A. Effect of electrical stimulation of goat muscles with respect to its sensory properties on post-ES storage at ambient temperature

Sensory property studied	Score NS	SE	Score ES	SE	Test of significance at 5% level
Tenderness	4.93	0.15	5.97	0.22	Significant
Flavour	4.87	0.09	5.02	0.09	Not significant
Juiciness	4.78	0.13	5.10	0.14	Not significant
Connective tissue residue	5.04	0.16	5.88	0.14	Significant
Overall acceptability	5.12	0.17	6.06	0.20	Significant

Treatments: NS = Not stimulated

ES = Electrically stimulated

All scores are Mean $\pm$ SE of scores given by 5 member taste panel for 10 observations each

Table 73. Effect of ES of goat muscles with respect to its sensory properties on post-35 storage by refrigeration

Sensory property studied	Score NS	SE	Score ES	SE	Test of significance at 5% level
Tenderness	4.98	0.18	6.12	0.18	Significant
Flavour	4.86	0.10	5.10	0.12	Not significant
Juiciness	4.80	0.14	5.14	0.11	Not significant
Connective tissue residue	4.94	0.22	5.90	0.26	Significant
Overall acceptability	5.06	0.19	6.10	0.15	Significant

Treatments : NS = Not stimulated
ES = Electrically stimulated

All scores are mean ± SE of scores given by 5-member taste panel for 10 observations each

Discussion

5. DISCUSSION

5.1. Visible changes

Electrical stimulation of goat carcass sides employing alternating current at 150 volts, 50 Hz frequency, 20 pulses per second and a stimulation cycle of 1 sec. 'on' and 2 sec. 'off' resulted in visible indications of effective stimulation in the carcass sides. The intense movements noticed in the carcass sides during the initial 60 sec. of stimulation subsided towards the end of the 120 sec. stimulation period, possibly due to depletion of the muscles' energy sources (Bendall, 1980) and reduction in the excitability of the cell membranes (Guyton, 1966). The post-exsanguination delay of 18-25 minutes before stimulation did not affect the efficiency of stimulation as all carcass sides responded to ES with physical movements. Shorthose et al. (1986) had suggested that ES should be carried out within 30 minutes of slaughter, in order to have maximum effects.

5.2. Changes in pH

The mean initial pH in LD muscles of goats was 6.453 ± 0.079. In the stimulated carcasses, the pH measured at 1 hr, 2 hr, 3 hr and 4 hr were significantly lower than the corresponding values for the NS carcasses. But at 8 hr, 12 hr and 24 hrs, there were no significant differences in pH between NS and ES muscles. Similar reports of accelerated initial fall in pH attributable to ES have been made by many workers like Bouton et al. (1978), Chrystall and Devine (1978), Chrystall

et al. (1984), Dikeman et al. (1985), Solomon et al. (1986) and Smulders (1987).

During the 2 minutes period of stimulation, the muscle pH dropped sharply by 0.425 pH units. Chrystall and Devine (1978) reported a fall in pH of 0.2 to 0.7 pH units during ES in beef.

After the period of stimulation, the pH in the ES muscles stored at ambient temperature fell subsequently from 6.028 to 5.652 (0.376 pH units) in four hours. The pH in the NS muscles fell from 6.453 to 5.932 (0.521 pH units) during the same period. In the refrigerated samples, the pH fell by 0.247 and 0.354 pH units in the ES and NS muscles respectively. This slower rate of fall in pH in the ES muscles compared to NS muscles, during the 4 hours after stimulation is not in agreement with the reports in beef by Chrystall and Devine (1978) and in sheep by Newbold and Small (1985) who observed significantly faster rate of fall in pH in the ES muscles during the post-ES period. This may be due to an initial steep fall in pH during ES and subsequent slowing down of pH fall in the stimulated muscles, while the pH in NS muscles had a steady fall.

In the ES muscles stored at ambient temperature, the pH fell below 6.0 within 1 hr after stimulation. But in the corresponding NS muscles, it took nearly 4 hours for the pH to reach 6.0. This is in agreement with findings of Bendall (1980) who reported that in ES muscles the pH dropped to 6.0 in 1.2 hours after ES and Eikelenboom and Smulders (1986) who

achieved pH below 6.0 within 45 minutes post-mortem in stimulated veal.

The ultimate pH of 5.6 was reached by 4 hours in the ES muscles stored at ambient temperature compared to the NS muscles in which ultimate pH was reached by 12 hours. In the refrigerated ES muscles the ultimate pH was reached at around 8 hours and in the corresponding NS muscles at around 12 hours. Thus the fall in pH is found to be slower under refrigerated storage condition compared to storage at ambient temperature. This can be attributed to temperature dependent enzymatic action. For attaining the ultimate pH in the stimulated beef muscles, the time reported by Bendall (1980) was 2.3 hours. Unruh et al. (1986) achieved ultimate pH in stimulated beef carcasses at 2 hours compared to 8 hours in NS muscles.

5.3. Glycogen content

The initial glycogen content in the LD muscles of goats ranged between 0.527 and 1.06 g per 100 g wet muscle (mean 0.788 $\pm$ 0.055 g %). In the stimulated carcasses the glycogen content had fallen by 29.8% during the period of stimulation. During the post-stimulation period there was a progressive reduction in glycogen content with advancing time. The estimated values of glycogen at 2 hr, 4 hr and 8 hr were significantly lower in the ES muscles compared to NS muscles. At 8 hrs the NS muscles stored at ambient temperature showed a depletion of 49.7% glycogen compared to 68.3% depletion in the corresponding ES muscles. Chrystall and Hagyard (1976)

and Davey et al. (1976) reported accelerated glycolysis due to ES but no reports are available on the quantitative analysis of glycogen at time intervals. The present study has thus quantitatively shown that there is accelerated glycolysis due to ES.

Chi square test indicated that the rate of fall in pH and the rate of fall in glycogen content in LD muscles are independent of each other. Seideman and Cross (1982) stated that since numerous antemorten and post-mortem factors affect the rate of glycolysis, the effectiveness of ES may not be measured by the rate of glycolysis alone.

5.4. Sarcomere length

The mean initial sarcomere length in LD muscles of goat carcasses was 1.41 ± 0.05 um. The sarcomere length measured immediately after ES (1.53 ± 0.03 um) did not differ significantly from the initial values. After 12 hours storage at ambient temperature the ES muscles had significantly longer sarcomeres (1.62 ± 0.05 um) when compared to the corresponding NS muscles (1.39 ± 0.05 um). Similarly the ES muscles had significantly longer sarcomeres compared to NS muscles after 12 and 24 hours of refrigeration.

This increase in sarcomere length in ES muscles compared to NS muscles after storage, is in agreement with the reports of Savell et al. (1977), Bouton et al. (1978), George et al. (1980), Gigiel and James (1984), Takahashi et al. (1984) and Prabhakar et al. (1986), who demonstrated longer sarcomeres

associated with ES. But McKeith et al. (1979) reported that goat carcasses chilled at 1°C after ES had identical sarcomere length of 1.58 um as in NS carcasses similarly chilled. Similar reports of ES having no effect on sarcomere length have been made by Savell et al. (1978, 1979), Will et al. (1979), Attrey (1980), Elgasim et al. (1981) and Salm et al. (1981).

Salm et al. (1983) attributed the increase in sarcomere length of stimulated muscles to the effect of ES in preventing cold shortening. In the present study the observed difference in the sarcomere length of NS and ES muscles under refrigeration could be related to some degree of cold shortening in the refrigerated NS muscles and the absence of it in the ES muscles. The increased sarcomere length observed in ES muscles stored at ambient temperature compared to NS muscles might be due to the accelerated aging in stimulated muscles brought about by the earlier and faster autolytic enzyme activity (Dutson et al., 1980).

5.5. Fibre diameter

The mean initial fibre diameter of LD muscles from goat carcasses was 63.46 ± 2.70 um. Immediately after ES, the fibre diameter was 63.2 ± 2.06 um, which was not significantly different from the initial value. After storage for 12 hours at ambient temperature, there was no significant difference in the fibre diameter of NS and ES muscles. Similarly the refrigerated samples had no significant difference between the fibre diameter

of NS and ES muscles both at 12 and 24 hours. However, the values for ES muscles tended to be lower compared to NS muscles on all measurements.

Herring et al. (1965) had stated that when muscles shorten there is a corresponding decrease in sarcomere length and an increase in fibre diameter. Therefore a negative correlation between sarcomere length and fibre diameter was expected in the study. In the NS muscles there was a negative correlation between these parameters on storage at ambient temperature (-0.702, $P<0.05$) and also under refrigeration (-0.643, $P<0.05$). But the ES muscles showed no such correlations. Reports on the influence of ES on fibre diameter are not seen published.

5.6. Water Holding Capacity

There were no significant differences in the water holding capacity of NS and ES muscles at 0 hr, 4 hr and 12 hr under both storage conditions. However, after 24 hours of refrigeration, the ES muscles had significantly lower WHC compared to NS muscles. Similar reports of reduced WHC in ES muscles have been made by Martin et al. (1983), Duts et al. (1986), Oreshkin et al. (1986), Unruh et al. (1986), Snulders and Dikelenboom (1986) and Mahajan and Panda (1989A). But many workers including George et al. (1980), Dutson et al. (1980), and Honikel and Reagen (1986) reported that ES did not result in significant changes in WHC in the muscles. Reports on improvement in WHC attributable to ES have been made by Hostetler et al. (1972)

Hopkinson et al. (1985), Jones et al. (1986) and Prabhakar et al. (1986).

The lower WHC observed in the ES muscles after 24 hrs of refrigerated storage compared to NS muscles could be due to the denaturation of sarcoplasmic proteins by the rapid pH fall induced by ES (Eikelenboom and Smulders, 1986) and the increase in permeability of myofibrillar cell membranes after storage (George et al., 1980).

5.7. Extract Release Volume

The stimulated LD muscles had significantly higher ERV measured immediately after ES compared to the initial values. After 12 hrs storage at ambient temperature, the ES muscles had significantly higher ERV than the NS muscles. These observations are in agreement with the reports of Mahajan and Panda (1989A) who demonstrated higher values of ERV in ES muscles compared to NS muscles at 8 hours post-stimulation. These workers attributed the difference in ERV to faster biochemical changes caused by ES.

The refrigerated NS and ES samples did not differ in ERV when measured at 12 and 24 hours. Cook (1968) had stated that at reduced pH, there are changes in the properties of proteins which resulted in alteration in the water binding ability of the proteins. At refrigerated storage, the pH fall was at a slower pace compared to that stored under ambient temperature and the biochemical activities were also at lower rate. Thus there is

no appreciable differences in DRV in the refrigerated NS and ES muscles.

5.8. Sensory evaluation

There were significantly higher taste panel scores for tenderness, sensory connective tissue and overall acceptability in the stimulated muscles when compared to the non-stimulated (control) muscles. But flavour and juiciness scores were not significantly different in NS and ES muscles.

5.8.1. Tenderness.

In the samples stored at ambient temperature, the ES muscles had a 21.1% higher tenderness rating compared to NS muscles. Similarly the refrigerated ES muscles had 22.9% more tenderness than the corresponding NS muscles. This is in agreement with the observations of Savell (1979) who reported 20% improvement in sensory tenderness in beef carcasses due to ES, Rashid et al. (1983) observing 15% more tenderness in stimulated lamb carcasses and Smith (1985) who stated that stimulated goat carcasses had improved in tenderness by 32%. However, Taylor et al. (1981), Griffin et al. (1981), Wood and Froehlich (1983) and Riley et al. (1983) failed to observe any difference in tenderness between NS and ES muscles. Takahashi et al. (1984) and Dikeman et al. (1985) reported detrimental effects on tenderness due to ES.

The mechanism of action by which ES influenced tenderness have been variously explained by different workers. Carse (1973),

Chrystall and Hagyard (1976) and Davey et al. (1976) attributed the improved tenderness in stimulated muscles to the rapid pH decline and the resultant prevention of cold shortening. But Marsh (1983) and Takahashi et al. (1984) demonstrated that the rapid glycolysis brought about by ES was detrimental to tenderness. These workers stated that other actions usually accompanying the rapid fall in pH like extensive disruption of the tissue structure were responsible for the net advantage from ES. Savell et al. (1978), Marsh et al. (1981) and Sorinmade et al. (1982) had also related the improved tenderness due to ES with tissue disruption. Sorinmade et al. (1978), Dutson et al. (1980) and Judge et al. (1980) attributed the tenderising effect of ES to the increased proteolytic enzyme activity.

Unruh et al. (1986) was of the opinion that the tenderization due to ES cannot be attributed to any single factor but was a result of the combined effect of factors like prevention of cold shortening, accelerated enzyme activity and disruption of tissue structure.

The positive correlation observed between tenderness scores and sensory connective tissue rating (lower amount of connective tissue residue) in refrigerated ES muscles and the absence of such correlation in corresponding NS muscles suggest that the higher tenderness scores obtained in the refrigerated ES muscles may possibly be due to the effect of ES on the connective tissue (Judge et al., 1980).

The tenderness scores obtained for NS muscles stored at ambient temperature (hot-tenderized) and ES muscles similarly stored were 5.12 ± 0.17 and 6.06 ± 0.20 respectively. These values are significantly different and indicate that ES is more effective in improving tenderness than hot tenderization of chevon from old animals.

5.8.2. Flavour.

The flavour scores for stimulated muscles were not significantly different from that of NS muscles. Similar observations were made by Smith et al. (1979), Salm et al. (1981), Crouse et al. (1983), Greathouse et al. (1983), Wood and Froehlich (1983) and Solomon et al. (1986). Davey et al. (1976) and Savell et al. (1977, 1978 and 1979) have also reported that ES did not affect flavour rating of meat from lamb or goat, although there was increase in flavour rating in beef.

The post-slaughter breakdown products of ATP and CP are responsible for the characteristic meat flavour. Savell (1979) attributed a 10.4% improvement in flavour of stimulated beef to more complete breakdown of ATP to hypoxanthene by ES. Calkins et al. (1981) also reported that ES significantly enhanced the breakdown of ATP and other adenine nucleotides. However, these workers observed no differences in the amount of ATP, AMP or inosinates, or in the sensory panel ratings for flavour between NS and ES muscles after 7 days aging.

5.8.3. Juiciness.

There were no significant differences in juiciness scores between the NS and ES muscles. Though in the samples stored at ambient temperature the ES muscles tended to have higher scores for juiciness (5.10 ± 0.14) when compared to the scores for NS muscles (4.78 ± 0.13), these differences were not significant. Similar trend was observed in the refrigerated samples also. The results were in agreement with the findings of Elgasim et al. (1981), Griffin et al. (1981), Salm et al. (1981) and Wood and Froehlich (1983) who reported that ES had no significant effect on the juiciness in muscles. But Crouse et al. (1983) and Unruh et al. (1986) had observed slightly decreased juiciness in stimulated beef carcasses compared to NS carcasses. The latter workers attributed the difference in juiciness to the rapid fall in pH induced by ES.

A positive correlation of juiciness with sensory connective tissue rating (lesser amount of connective tissue residue) was noticed in all groups of muscles studied. This may be due to the better sensory perception of juiciness by the relatively lower connective tissue residue resulting from the physical damage of the connective tissue by ES (Seideman and Cross, 1982) and the lowered collagen cross-linking brought about by stimulation (Judge et al., 1980).

5.8.4. Sensory connective tissue.

Sensory connective tissue indicate residue in meat after chewing. Higher the score, lesser the residue and vice-versa.

The rating for sensory connective tissue in the ES muscles was significantly higher when compared to NS muscles. In the samples stored at ambient temperature the ES muscles had a sensory connective tissue score of 5.88 ± 0.14 which was about 16.7% higher than the rating for corresponding NS muscles (5.04 ± 0.16). Similarly in the refrigerated samples the rating of ES muscles was 5.90 ± 0.26 which was 19.4% higher than the rating for corresponding NS muscles (4.94 ± 0.22). These findings are in agreement with the observations made by Savell et al. (1977, 1978, 1979 and 1981), Riley et al. (1981), Ray et al. (1983) and Vanderwert et al. (1986). However, Solomon (1986A) reported that no significant differences due to ES were detected in sensory connective tissue ratings.

The observed higher sensory connective tissue rating due to ES may be attributed to a lowering of collagen cross-linking during ES and a decrease in thermal stability of intramuscular collagen (Judge et al., 1980; and Etherington, 1984) resulting in a lower residue.

The positive correlation of sensory connective tissue rating observed with tenderness scores and overall acceptability scores indicate the role of connective tissue in sensory evaluation and the beneficial effect of ES.

5.8.5. Overall acceptability.

The overall acceptability scores were significantly higher in the ES muscles compared to the NS muscles. In the samples

stored at ambient temperature, the ES muscles had an overall acceptability score of 6.06 ± 0.2 which was higher by 18.4% than the score for NS muscles (5.12 ± 0.17). Similarly the overall acceptability of refrigerated ES muscles (6.1 ± 0.15) was 20.6% more than the corresponding NS muscles (5.06 ± 0.19).

Improvement in overall acceptability in stimulated muscles, has been reported by many workers including Savell et al. (1979), Riley et al. (1981), Hopkinson et al. (1985) and Smulders et al. (1986). But Dikeman et al. (1985) reported that ES had a detrimental effect on meat palatability and overall acceptability in beef carcasses. Digasin et al. (1981), Wood and Froehlich (1983), Crouse et al. (1983) and Bidner et al. (1985) observed no significant differences in overall acceptability in ES carcasses when compared to NS carcasses.

The correlation studies indicate that overall acceptability in all groups of muscles were positively correlated with tenderness. In the NS muscles, overall acceptability had positive correlation with tenderness, sensory connective tissue rating, flavour and juiciness. In the ES muscles overall acceptability had positive correlation with tenderness, sensory connective tissue rating and flavour, but not with juiciness.

The results of the present study indicate that ES improved the overall acceptability of chevon from old animals.

Summary

SUMMARY

Electrical stimulation of split goat carcasses was carried out using a locally fabricated stimulator. The equipment delivered pulsed alternating current at 150 volts, 50 Hz, 20 pulses per second and a stimulation cycle of two seconds 'on' and one second 'off'. The total duration of stimulation was 120 seconds. The post exsanguination delay for stimulation ranged from 18 to 25 minutes. The carcass sides were suspended from an earthed rail (linked with earth circuit) by means of stainless steel hooks attached to the achilles tendon. A single copper electrode measuring 20 cm in length and 0.6 cm in diameter was inserted into the muscles between the scapula and thoracic vertebrae and it acted as the live electrode. The earthed rail served as the ground (earth).

Samples of Longissimus dorsi muscles were collected from both stimulated and non-stimulated sides and were stored (a) at ambient temperature upto 12 hours and then refrigerated upto 24th hour, (b) at refrigeration temperature after one hour of ES upto 24 hours. The muscles were examined at specified time intervals for changes in pH, glycogen content, sarcomere length, fibre diameter, water holding capacity and extract release volume. Sensory evaluation was conducted after 24 hours by a 5-member semi-trained taste panel. The data was statistically analysed and the results were interpretted.

The carcass sides responded to ES by visible flexion of

the forelimbs, raising of the neck region due to vigorous bending of the thoracic and cervical regions and contraction of the muscles of the neck, trunk and thigh regions.

The mean initial pH in the muscles was 6.453. After two minutes stimulation, the pH dropped by 0.425 pH units. The ultimate pH in the stimulated muscles was reached earlier than in NS muscles. The rate of fall in pH during the four hours after stimulation was slower in ES muscles when compared to NS muscles.

Estimation of glycogen content was done at time intervals upto 8 hours. The glycogen content in the ES muscles was lower compared to NS muscles at all time intervals studied. It was concluded that ES accelerates the rate of glycolysis.

The sarcomere length in the stimulated muscles were higher on storage compared to NS muscles. But the fibre diameter did not differ significantly between NS and ES muscles. Lower water holding capacity was observed in ES muscles compared to NS muscles, after 24 hours storage under refrigeration. However higher values of DRV in ES muscles were observed during initial stages after ES and not after 24 hours of refrigeration.

The taste panel studies indicated that the stimulated muscles stored at ambient temperature had 21.1% higher tenderness score compared to NS muscles. Similarly, ES muscles stored under refrigeration had 22.9% improvement in tenderness compared to NS muscles. The connective tissue ratings were 16.7 and

19.4 per cent higher in stimulated muscles stored at ambient and refrigeration temperatures respectively than corresponding NS muscles. There was no significant difference in flavour and juiciness scores between NS and ES muscles. The overall acceptability of stimulated and non-stimulated muscles showed significant differences. For the stimulated muscles it was 18.4 and 20.6 per cent higher under ambient and refrigeration temperatures respectively than NS muscles.

It was concluded that electrical stimulation results in acceleration in the rate of glycolysis, a sudden drop in pH during stimulation and early attainment of ultimate pH. ES influenced sarcomere length, water holding capacity and DRV. Improvements in tenderness, connective tissue rating and overall acceptability are observed as a result of electrical stimulation. But flavour and juiciness ratings are not significantly altered due to stimulation.

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Appendices

APPENDIX A

Procedure for estimation of glycogen content (Seifter et al., 1950)

Principle:

The muscle tissue is digested with potassium hydroxide and the digesta treated with Anthrone reagent. The Sulphuric acid medium of Anthrone reagent causes dehydration of the sugar to a furfural derivative which presumably condenses with Anthrone to form a blue coloured compound. The colour produced is compared in a colorimeter with that of the standard glucose solution treated identically.

Reagents:

1. Potassium hydroxide solution 30 per cent:-
   300 g of reagent grade potassium hydroxide pellets were dissolved in distilled water in a beaker, cooled, transferred quantitatively to a litre volumetric flask and diluted to the mark with distilled water.

2. Sulphuric acid, 95 per cent:-
   To 50 ml of distilled water, one litre of conc. sulphuric acid (specific gravity 1.84) was added carefully.

3. Anthrone reagent, 0.2 per cent:-
   0.2 g of Anthrone was dissolved in 100 ml of sulphuric acid. This reagent was always prepared fresh.

4. Standard glucose solution:-
   A stock standard of glucose solution was prepared by dissolving one g of highest purity anhydrous glucose in

Appendix A contd.

saturated benzoic acid solution and diluting to 100 ml with the same. A working standard was prepared from this by diluting one millilitre to 500 ml with distilled water. Five ml of this working standard contained 100 microgrammes of glucose.

Procedure:

About one gram of muscle tissue was excised and transferred into a weighed test tube. The tube and the contents were weighed again. The weight of the sample taken was obtained by difference. About three ml of potassium hydroxide solution were added into the test tube. The tissue was then digested by heating the tube for 20 minutes in a boiling water bath. After cooling, the contents were transferred quantitatively to a 250 ml volumetric flask, made up the volume with distilled water and mixed thoroughly.

Five ml of the diluted digesta was pipetted into a labelled tube. Five ml of working standard, and 5 ml of distilled water were taken to two other test tubes marked standard and blank respectively. The unknown, standard and blank were then kept in an ice-cold water bath. By careful mixing, added 10 ml of Anthrone reagent to each tube from a fast flowing burette. After cooling, the tubes were placed in a boiling water bath for 10 minutes. The tubes were immediately cooled in running water. The readings of standard and unknown were taken in a Spectrophotometer ('Spectronic 20" - Bausch and Lomb) at a wave

Appendix A contd.

length of 595 millimicrons; after setting the instrument to 100 per cent transmittance with the blank.

Calculation

$$\text{Glycogen content g/100 g wet tissue} = \frac{U \times CS \times 250 \times 100}{S \times 1.11 \times 5 \times W \times 1000 \times 1000}$$

where,

U = reading of unknown

S = reading of standard

W = weight of tissue taken

CS = concentration of standard in micrograms

1.11 = the factor used to convert glucose into glycogen

$\frac{250}{5}$ = dilution factor

$\frac{100}{1000 \times 1000}$ = factor for expressing the value in g per cent

APPENDIX B

ERV Reagent (Pearson, 1976)

Preparation:

i) 0.2 M potassium dihydrogen phosphate (KH_2PO_4) was prepared by dissolving 2.72 g of the reagent in 100 ml distilled water.

ii) 0.2 M sodium hydroxide (NaOH) was prepared by dissolving 0.8 g NaOH in 100 ml distilled water.

iii) 3.72 ml of the 0.2 M sodium hydroxide solution was added to 50 ml of 0.2 M potassium dihydrogen phosphate solution. The volume was made upto 200 ml with distilled water. The pH was adjusted to 5.8.

APPENDIX C

Score Card (Scale 1-9 scores)

Name Date Exp. No.

Sample No.	Tender-ness	Flavour	Juiciness	Connective tissue residue	Overall accepta-bility
1.					
2.					
3.					
4.					

High - 7-9 Medium - 4-6 Low - 1-3

Tenderness	1 = extremely tough 9 = extremely tender
Flavour	1 = extremely bland 9 = extremely intense
Juiciness	1 = extremely dry 9 = extremely juicy
Connective tissue residue	1 = abundant 9 = absent
Overall acceptability	1 = not acceptable 9 = highly acceptable

EFFECT OF ELECTRICAL STIMULATION ON CHEVON QUALITY

By

MAJOR EMMANUEL MATHEW

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Veterinary Science

Faculty of Veterinary and Animal Sciences
Kerala Agricultural University

Department of Veterinary Public Health
COLLEGE OF VETERINARY AND ANIMAL SCIENCES
Mannuthy, Thrissur

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ABSTRACT

Electrical stimulation of carcasses is considered as a means of improvement in meat quality. The present study was undertaken to determine the effects of ES on goat carcasses and to observe improvement in meat quality, if any.

The study was conducted on longitudinally split carcasses of ten adult goats (aged 8-11 years) by stimulating one half from each carcass while the other half served as control. ES was done within 25 minutes of exsanguination using pulsed alternating current at 150 volts, 50 Hz, and 20 pulses per second and with a stimulation cycle of two seconds 'on' and one second 'off', for a total duration of 120 seconds.

Samples of Longissimus dorsi muscles were collected from both stimulated and non-stimulated sides and stored at ambient and refrigeration temperatures. They were subjected to study the changes in pH, glycogen content, sarcomere length, fibre diameter, water holding capacity and extract release volume at specified time intervals. Sensory evaluation was done 24 hours after ES.

The main observations were rapid drop in pH during stimulation, early attainment of ultimate pH, slower rate of pH fall during post-stimulation period, accelerated rate of glycolysis, increase in sarcomere length, lower WHC and initial increase in ERV in stimulated muscles when compared to NS muscles. There was no significant difference in fibre diameter.

Taste panel studies indicated significant improvement in tenderness of stimulated muscles stored at ambient and refrigeration temperatures. The connective tissue ratings were also significantly favourable for ES muscles stored at both temperatures. The overall acceptability improved markedly in the case of stimulated muscles than in NS muscles. There were no changes in flavour and juiciness ratings attributable to electrical stimulation.