INFLUENCE OF DIETARY ENERGY AND POSTMORTEM ELECTRICAL STIMULATION ON MEAT QUALITY AND COLLAGEN CHARACTERISTICS OF LAMB CARCASSES

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Summary

Sixty ram lambs, weighing 23.5 kg, were randomly assigned in a 2 × 3 factorial arrangement of two dietary energy (high; 11.7 and low; 9.0 MJ ME/kg DM) and three levels of poultry offal meal supplementation (0, 5 and 10%). Lambs were fed *ad libitum* for 120-day before salughter. At slaughter, half the lambs in each dietary treatment group were randomly selected for electrical stimulation of their undressed carcasses. The M. Biceps femoris pH and temperatures were monitored at 1, 3, 5, 8 and 24 h postmortem. At 24 h postmortem, the M. biceps femoris was removed from the right side of each carcass and steaks were obtained for determination of Warner-Bratzler shear force, collagen content and collagen solubility. The results showed that temperature and pH values during the 24-h postmortem were consistently higher ($p < .01$) and lower ($p < .01$), respectively, for M. biceps femoris from lambs fed high energy diets than for those fed on low energy diets. Muscles from high energy fed lambs had lower ($p < .01$) shear force values and higher ($p < .01$) percent solube collagen than for low energy fed lambs; total collagen content was not significantly influenced by dietary energy level. Increased the level of poultry offal meal supplementation in the diet to 10% was associated with concomitant increases ($p < .01$) in muscle tenderness and percent soluble collagen. Electrical stimulation (ES) of carcasses resulted in a lower shear force values for the M. biceps femoris than in non-stimulated carcasses (Non-ES); total collagen content and percent soluble collagen were not significantly affected by ES treatment.
(**Key Words** : Dietary Energy, Poultry Offal, Electrical Stimulation, Collagen)

Introduction

Postmortem biochemical changes in muscle that contribute to meat tenderness and creation of proper conditions for optimum eating quality may be temperature- and pH-dependent (Martin et al., 1983). Bendall (1972) concluded that the rapid lowering of pH in association with high carcass temperature enhances meat tenderness. A practical method to achieve the formerly said condition is to apply the electrical stimulation on carcasses soon after the slaughter of animals. Electrical stimulation had resulted in marked tenderization of lamb carcasses (Chrystall and Hagyard, 1976; Hagyard et al., 1980; Chrystall et al., 1984) by causing early rigor and increased rate of pH and glycogen decline (Newbold and Small, 1985), thereby preventing toughening due to cold shortening.

Intensive pre-slaughter feeding has a beneficial effect on the sensory properties and meat tenderness of lambs; lambs fed on a high nutritional plane produced more tender meat than those fed on a low plane (Leander et al., 1978; Miller et al., 1987). Yet others have reported no effect of diet on meat tenderness (Burson et al., 1980; Kirton et al., 1981). Furthermore, studies have associated increases in collagen solubility with the feeding of high energy diets (Aberle et al., 1981; Miller et al., 1987). The objective of this study was to explore the effects of electrical stimulation treatment on meat quality and collagen characteristics from Najdi ram lambs fed either a high or low energy diet.

Materials and Methods

Sixty Najdi ram lambs, of mean initial live weight 23.5 kg and 3.5 months old, were randomly assigned to one of six dietary treatment groups in a 2 × 3 factorial

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arrangement of two levels of dietary energy (high; 11.7 and low; 9.0 MJ ME/kg DM) and three levels of poultry offal meal supplementation (0, 5, and 10%). All experimental diets were isonitrogenous and diets within each dietary energy level were isocaloric (table 1). Lambs were individually fed *ad libitum* in shaded pens on concrete, and water was always available. Daily feed intakes were recorded and animals were weighed at 14-day intervals for the duration of the 120-day feeding period. Upon completion of the feeding period, lambs were removed from feed 18 h prior to slaughter.

TABLE 1. INGREDIENTS AND COMPOSITION OF EXPERIMENTAL DIETS[a]

Ingredients (%)	High energy			Low energy		
	Level of poultry offal meal (%)					
	0	5	10	0	5	10
Poultry offal meal	–	5.0	10.0	–	5.0	10.0
Soybean meal	10.0	5.0	–	10.0	5.0	–
Barley	29.3	34.0	38.0	4.5	9.2	13.0
Corn starch	8.7	4.0	–	8.5	3.8	–
Yellow corn	20.5	20.5	20.5	–	–	–
Wheat straw	6.1	10.1	13.6	28.4	32.4	35.4
Alfalfa hay	23.9	19.9	16.4	48.1	44.1	41.1
Salt	0.47	0.47	0.47	0.47	0.47	0.47
Trace mineral premix[b]	0.03	0.03	0.03	0.03	0.03	0.03
Sodium bicarbonate	1.0	1.0	1.0	–	–	–
CP (%)	14.9	14.9	14.9	14.9	14.9	14.9
Ca (%)	0.40	0.53	0.66	0.76	0.89	1.02
P (%)	0.31	0.39	0.46	0.22	0.29	0.36
ME/kg DM(MJ)	11.7	11.7	11.7	9.0	9.0	9.0

[a] Dry matter basis.
[b] Contained 10% Mn, 10% Fe, 10% Zn, 1% Cu, 0.3% I and 0.1% Co.

At slaughter time, half of the lambs in each of the six dietary treatment groups were randomly selected for electrical stimulation treatment. Stimulation was applied at 2-5 min postslaughter using two copper electrodes placed in the rectum and neck regions of the undressed carcass. The electrical stimulation unit used was a 220 V, 2.5 amps and 60 Hz of alternating current; the current was pulsed 2s on and 1s off for total of 1.5 min duration.

The lambs were reared and slaughtered at the Experimental Livestock Farm, King Saud University. Hot carcass weight 30 to 45 min after slaughter was recorded; tail fat was removed and weighed. Thereafter, the carcasses both stimulated and unstimulated were hung from the Achilles tendon and transported to the chiller held at 10℃ until 24 h postmortem before ribbing between the 12th and 13th ribs. Fat thickness over the center of the M. Longissimus dorsi was measured. Also, the M. biceps femoris from the right side of each carcass was removed, sliced into three 2-cm thick steaks, wrapped in stockinet and frozen at −20℃ pending analysis.

The progress of glycolysis was followed through measurement of the pH of M. biceps femoris muscles in all carcasses, was determined by inserting a combination glass probe electrode into a freshly-made cut each time. The temperature of the muscles were monitored by thermocouple probe inserted into the M. biceps femoris. Measurements of pH and temperature began after dressing and were continued for 24 h on all carcasses held at 10℃; the measurements were determined at 1, 3, 5, 8 and 24 h postmortem at about 5 cm below the surface.

Shear force (expressed in kg/cm^2) was performed on biceps femoris muscle steaks cut to a 2-cm thickness and thawed overnight at 2℃. The steaks were broiled to an internal temperature of 70℃, as determined by use of copper constantan thermocouple and were allowed to cool to room temperature for 4 h. Four cores per steak, each core 1.27 cm in diameter, were removed parallel to the muscle fibers, subjected to a Warner-Bratzler shear machine. Collagen content and solubility were determined according to procedures of Bergman and Loxley (1963).

Feeding performance, carcass traits and M. biceps femoris muscle traits data were analyzed statistically by analysis of variance and least-square analysis using the GLM, fixed-model procedures (SAS, 1986). The independent variables in the model included main effects of POM supplementation, dietary energy and electrical stimulation treatment and their interactions.

Results and Discussion

In order to describe adequately the lambs used for this study various performance and carcass traits were recorded for each lamb; thereafter, least-squares means as influenced by POM supplementation, dietary energy and ES treatment are presented in table 2. Lambs fed the 10% POM supplemented diet had higher ($p < .01$) average daily gain and heavier tail fat resulting in heavier slaughter and carcass weights. In addition, fat thickness was thicker ($p > .01$) for the lambs receiving the 10% POM supplementation than for those on the 5% POM supplemented diet. Previous research (unpublished data) had indicated numerous advantages in performance and carcass characteristics for lambs fed 5 and 10% POM supplemented diets over the 0% POM diet prior to slaughter. Although diets are isonitrogenous and isocaloric, the high amount of undegradable protein in POM (Annous, 1979) potentially has a positive effect on the quality of the supplemented diet for growing lambs. Lambs fed on high concentrate diets gained at a faster rate, produced heavier carcasses and tail fat with a thicker body fat layer than lambs fed on high roughage diets. Similar findings were reported by Solomon et al. (1986) who concluded that lambs fed on high energy diets typically were heavier, more efficient grower and produced carcasses with higher amounts of fat and protein as compared to those produced by lambs fed on lower energy roughage-based diets. Differences due to ES treatment were not observed for any of the studied traits.

Means for M. biceps femoris pH and temperature values by POM supplementation level, dietary energy and stimulation treatment are presented in table 3. Apparently, pH values, from 1 hr through 24 h postmortem, were consistently lower ($p < .01$) for M. biceps femoris from lambs fed 10% POM supplementation than for those fed 0 and 5% POM supplemented diets. The ultimate pH value

TABLE 2. LEAST-SQUARE MEANS FOR CARCASS CHARACTERISTICS AND PERFORMANCE AS INFLUENCED BY POULTRY OFFAL MEAL SUPPLEMENTATION (POM), DIETARY ENERGY AND ELECTRICAL STIMULATION TREATMENT (ES) IN NAJDI LAMBS

Traits	POM (%)			Dietary energy		ES treatment		SEM
	0	5	10	High	Low	Non-ES	ES	
No. lambs	20	20	20	30	30	30	30	
Slaughter wt (kg)	40.1^c	42.2^b	44.9^a	47.3^a	37.5^b	42.6	42.2	1.1
Average daily gain (g)	138^b	155^{ab}	178^a	198^a	116^b	156	158	7.8
Daily dry matter intake (g)	1,134	1,149	1,189	$1{,}249^a$	$1{,}065^b$	1,149	1,165	52.1
Hot carcass wt (kg)	19.0^b	19.9^b	21.4^a	24.1^a	16.0^b	19.6	20.5	0.8
Tail fat (kg)	2.25^c	2.40^b	2.52^a	3.26^a	1.52^b	2.45	2.33	0.1
Fat thickness (cm)	0.46^b	0.50^{ab}	0.54^a	0.66^a	0.33^b	0.47	0.53	0.1

[a,b,c] Values in the same row, within an effect, bearing different superscripts are different ($p < .01$).

TABLE 3. LEAST-SQUARE MEANS FOR M. BICEPS FEMORIS pH AND TEMPERATURE VALUES AS INFLUENCED BY POULTRY OFFAL MEAL SUPPLEMENTATION (POM), DIETARY ENERGY AND ELECTRICAL STIMULATION TREATMENT (ES) IN NAJDI LAMBS

Time postmortem (h)	POM (%)			Dietary energy		ES treatment		SEM
	0	5	10	High	Low	Non-ES	ES	
				pH				
1	6.65^a	6.62^a	6.52^b	6.48^b	6.72^a	6.90^a	6.30^b	0.06
3	6.39^a	6.37^a	6.29^b	6.22^b	6.47^a	6.70^a	6.01^b	0.05
5	6.24^a	6.25^a	6.11^b	6.06^b	6.34^a	6.59^a	5.80^b	0.06
8	6.03^a	6.05^a	5.91^b	5.92^b	6.07^a	6.24^a	5.74^b	0.07
24	5.87^a	5.83^a	5.60^b	5.58^b	5.96^a	5.99^a	5.55^b	0.09
				Temperature				
1	34.6	34.8	34.7	36.4^a	32.8^b	32.6^b	36.6^a	0.36
3	28.0	29.0	29.7	30.3^a	27.5^b	27.6^b	30.2^a	0.48
5	22.3	22.3	22.7	25.0^a	19.8^b	19.9^b	24.9^a	0.54
8	13.0	13.4	13.8	15.1^a	11.7^b	12.0^b	14.8^a	0.48
24	3.8	3.9	4.5	5.6^a	3.2^b	3.9	4.9	0.21

[a,b] Values in the same row, within an effect, bearing different superscripts are different ($p < .01$).

for the M. biceps femoris from lambs fed 10% POM was 0.27 and 0.23 pH unit lower than for 0 and 5% POM diet lambs, respectively. Nevertheless, ultimate pH values for the three diet groups were below 6.0. Lamb carcasses from 10% POM fed group had slightly slower rate of temperature decline than those from 0 and 5% POM supplemented diet groups. Although the differences between the three groups were not significant, the M. biceps femoris temperature for the 10% POM group was slightly higher ($p > .01$) than the other two groups during the 24 h postmortem.

Temperature and pH values during the 24-h postmortem were consistently higher ($p < .01$) and lower ($p < .01$) respectively, for M. biceps femoris from lambs fed high energy diets than for those fed on low energy diets. Similar findings were reported in cattle (Schroeder et al., 1982) and camels (Basmaeil et al., 1991) that muscle temperatures from grain-fed animals declined slower and remained higher than forage-fed animals. The ultimate pH for the M. biceps femoris from high energy diet lambs was 0.38 pH unit lower than for low energy diet lambs. Similar results were reported by Solomon et al. (1986) who found that high-level-fed lambs had lower ultimate pH values than did the low-level-fed lambs. Muscle pH is considered to be a measure of postmortem muscle metabolism, and as a result can be used as an immediate indicator of the stage of postmortem glycolysis (Newbold and Small, 1985). It is possible that diet, more specifically the low energy diet, could have affected the level of glycogen in the muscles as described by Schroeder et al. (1982). They found that pH appeared to directly related to the intake of available carbohydrate from diet; animals fed high roughage diet had low concentrations of glycogen stores at the time of slaughter, resulting in higher pH for postmortem muscles. Accordingly, Asghar and Henrickson (1983) and Basmaeil et al. (1991) reported that muscles from underfed animals had slower rates of glycolysis than those from well-nourished animals.

A significant ($p < .01$) dietary energy × POM supplementation level interaction was observed for temperature and pH values. M biceps femoris from lambs fed high energy diets and receiving 5 and 10% POM supplementation had significantly ($p < .01$) higher temperatures and lower pH values throughout the 24 h postmortem than did the other studied groups. Differences in temperature and pH values due to POM supplementation in low energy diets were not significantly detected.

Electrical stimulation treatment (ES) resulted in a more rapid ($p < .01$) M. biceps femoris pH drop than the nonstimulated control lambs during the 24 h postmortem period. Increased rates of pH fall consistently coincided with increased muscle temperatures in ES lambs which, in turn reflects increased glycolytic rate. At 3 h postmortem, pH and temperature in the stimulated carcasses were 6.01 and 30.2°C, respectively. Combination of the results of pH and temperature measurements show that, in the nonstimulated control lambs the average pH was 6.24 at 8 h postmortem, while the temperature at the time was 12.0 °C in the M. biceps femoris. Accepting Bendall's (1972) description of cold shortening conditions as correct (temperature below 11°C before the pH has fallen below 6.2), cold shortening should not be present but was marginal in this group of lambs. There was a difference in ultimate pH value between ES and Non-ES groups ($p < .01$) which is unclear as it is not reflected in the temperature values.

A significant dietary energy × ES treatment interaction ($p < .01$) was detected for pH values. M. biceps femoris from lambs fed the low energy diet and received no electrical treatment did not reach an ultimate pH value below 6.0. Generally, the mean pH values of the electrically stimulated muscle from the low energy fed lambs during the 24 h postmortem period were from 0.12 to 0.23 pH unit lower ($p > .01$) than that of the nonstimulated muscle but considerably higher ($p < .01$) than both stimulated and nonstimulated muscles from the high energy fed lambs. Electrical stimulation treatment of muscles soon after slaughter causes a rapid fall in pH that is faster than in nonstimulated controls (Chrystall and Hagyard, 1976). Increased rate of pH fall reflects increased glycolytic rate in the muscles (Newbold and Small, 1985). Although muscle glycogen was not measured in this experiment, an important point to consider is the amount of glycogen necessary to potentiate the pH fall. This amount might vary between muscles from lambs fed different dietary energy because of variation in buffering capacity (Asghar and Henrickson, 1983). A possible explanation for the inability of pH values from the low energy fed lambs either electrically stimulated or nonstimulated to reach values below 6.15 after 5 h postmortem period is that the concentration of glycogen necessary to potentiate the maximal pH fall may have been low in the muscle.

Total M. biceps femoris collagen contents (table 4) from ram lambs segregated by level of POM supplementation, dietary energy and electrical stimulation treatment were similar ($p > .01$) and no consistent trend was evident among the nutritional regimens or ES treatment. These results agree with Hall and Hunt (1982) and Miller et al. (1987) who did not find significant differences in total collagen content between roughage- and concentrate-fed cattle.

During collagen synthesis, chemical bonds form between tropocollagen molecules providing reducible crosslinks which contribute to the organization and structural stability of collagen fibers. The proportion of these reducible intermolecular crosslinks gradually increase and stabilize to an insoluble form, causing a reduction in the amount of collagen that may be solubilized during subsequent cooking. However, soluble collagen represents the most recently synthesized collagen (Price and Schweigert, 1971). Table 4 showed that increased level of POM supplementation increased ($p < .01$) the percentage of newly synthesized soluble collagen. Shimokomaki et al. (1972) found that collagen crosslink stability was related more closely to the growth rate of the animal than to its age. Ram lambs fed 5 and 10% POM supplemented diets showed rapid rates of growth and, therefore, would be expected to produce lean with a high proportion of newly synthesized soluble collagen. Since collagen turnover normally is relatively slow (Dutson, 1976), any increase in synthesis rate should indeed increase the proportion of immature collagen. Aberle et al. (1981) demonstrated relationships among preslaughter feeding regimen, growth rate and collagen solubility and concluded that acceleration of growth via intensive feeding may exert a positive and direct effect on collagen solubility and tenderness of meat.

TABLE 4. LEAST-SQUARE MEANS FOR M. BICEPS FEMORIS COLLAGEN CHARACTERISTICS AND SHEAR FORCE VALUES AS INFLUENCED BY POULTRY OFFAL MEAL SUPPLEMENTATION (POM), DIETARY ENERGY AND ELECTRICAL STIMULATION TREATMENT (ES) IN NAJDI LAMBS

Traits	POM (%)			Dietary energy		ES treatment		SEM
	0	5	10	High	Low	Non-ES	ES	
Total collagen (mg/g)	4.73	4.32	4.64	4.51	4.61	4.49	4.63	0.05
Soluble collagen (%)	13.6^b	15.2^a	16.9^a	17.2^a	13.3^b	15.1	16.4	0.12
Shear force (kg/cm^2)	2.82^a	2.88^a	2.58^b	2.04^b	3.48^a	3.21^a	2.31^b	0.21

[a,b] Values in the same row, within an effect, bearing different superscripts are different ($p < .01$).

Increased dietary energy increased ($p < .01$) the percent soluble collagen in M. biceps femoris. This result agrees with Aberle et al. (1981), Hall and Hunt (1982) and Miller et al. (1987), who reported that intensive feeding may cause rapid rates of protein synthesis and thus produce muscles with a higher proportion of soluble collagen. However, the increase in percent soluble collagen from feeding a high-energy diets may greatly improve the tenderness of the lambs. Lambs fed a high plane of energy had M. biceps femoris that had lower ($p < .01$) WB-shear force values in comparison to the low plane of energy fed lambs. Additionally, increasing level of POM supplementation in the high energy diets decreased ($p < .01$) the WB-shear force values, contributing to the decreased stability of intermolecular collagen crosslinks (Miller et al., 1987).

Electrical stimulation did not affect the percent soluble collagen. Similar result was reported by Hawrysh et al. (1987). There was, however, a significant ($p < .01$) effect of electrical stimulation treatment on shear force values. ES carcasses had lower WB-shear force values for the M. biceps femoris than non-stimulated controls. Similar findings were reported by Hagyard et al. (1980), Chrystall et al. (1984) and Solomon et al. (1986), who found that muscles from carcasses that electrically stimulated were significantly more tender than the non-stimulated controls. Additionally, there was a significant interaction between electrical stimulation, dietary energy and level of POM supplementation for shear force ($p < .01$). The data of the various ES groups showed that the WB-shear force values were 0.8, 0.7 and 0.7 kg/cm^2 lower in high energy diets supplemented with 0, 5 and 10% POM, respectively, than in the corresponding low energy diets ($p < .01$). The electrically stimulated carcasses from the low energy fed lambs were more tender ($p < .01$) than the non stimulated controls. Generally, ES treatment improved the tenderness of M. biceps femoris from the low energy fed lambs by 41.1% in comparison to 27.3% in high energy fed lambs. Therefore, it can be concluded that the improvement of feeding levels as well as applying electrical stimulation treatment to low energy fed lambs proved to result a marked tenderization of its carcasses at least partly due to early rigor and/or an extra tenderising effect.

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