Effect of low voltage electrical stimulation and splitting the carcass on histochemical and meat quality characteristics of *Longissimus thoracis* muscle from the one-humped camel (*Camelus dromedarius*)

Kadim I. T. *, Mahgoub O., Al-Marzooqi O. W., Khalaf S. K.

Department of Animal and Veterinary Sciences, College of Agricultural and Marine Sciences, Sultan Qaboos University , PO Box 34, Al-Khoud 123, Muscat
Sultanate of Oman

Abstract

The aim was to study the effects of splitting carcasses and electrical stimulation (90 V) 30 min post mortem on meat quality and muscle fiber types of two age-group camels (1-2 and 8-10 years) were assessed. Two groups of 15 camels each, 1-2 and 8-10 years of age were assigned to one of four treatments: non-stimulated and electrically-stimulated; unsplit carcasses and split carcasses. The split carcasses were longitudinally split along the vertebral column and a low voltage electrical stimulation of 90 V, 14 Hz (pulse of 7.5 millisecond duration every 70 milliseconds for 60 seconds) applied 30 minutes post-mortem. The *longissimus thoracis* muscle pH, sarcomere length, myofibrillar fragmentation index, shear force, expressed juice, cooking loss and CIE L*, a*, b* colour values were measured. The histochemical staining properties of the myosin ATPase and succinate dehydrogenase were evaluated. Electrical stimulation resulted in a significantly ($P<0.05$) more rapid decline in muscle pH during the first 24 hours post-mortem. Muscles from stimulated samples had significantly ($P<0.05$) lower pH, longer sarcomere and lower shear values than those from non-stimulated ones. Expressed juice and myofibrillar fragmentation index were significantly ($P<0.05$) higher for stimulated than for non-stimulated samples. Meat from stimulated samples was significantly ($P<0.05$) lighter (L*) in colour than non-stimulated samples. There were no differences in muscle quality between split and unsplit carcasses. Muscles from 8-10 year old camels had significantly darker (L*), more red (a*), more yellow (b*) and higher pH and myofibrillar fragmentation index than those from 1-2 year old animals. Muscle samples from 1-2 year old camels had significantly ($P<0.05$) smaller muscle fibre diameters and a higher proportion of Types I muscle fibres and lower proportions of Types IIA and IIB than those from 8-10 year old camels. Low voltage electrical stimulation improved quality characteristics of meat from unsplit and split camel carcasses.

Key Words: Camel, electron microscope, *Longissimus thoracis*, muscle fiber type, meat quality

* Corresponding Author: I. T. Kadim, Tel: +968-2441534. Fax: +968-24423-418. Email: isam@squ.edu.om.

1. Introduction

The camel is an excellent source of high quality animal protein, provided with minimum resources (Kadim *et al.*, 2008b), in areas where the climate adversely affects other animals. Camel meat is also an ideal choice for health-conscious consumers due to its low fat content and rich polyunsaturated fatty acid content (Giese, 1992; Rawdah *et al.*, 1994; Dawood and Alkanhal, 1995). However, camel meat has been associated with low quality attributes because it comes mostly from older camels, primarily kept for milk and transportation rather than meat (Kadim *et al.*, 2008b). Quality characteristics of camel meat have received little attention and need to be established. An efficient marketing system for camel meat requires more information on meat quality characteristics.

Electrical stimulation is a proven method for improving meat quality characteristics by accelerating post-mortem pH decline, hasten rigor

development and improving certain palatability characteristics, especially tenderness (Kadim and Mahgoub, 2007, Kadim *et al.*, 2009a, b). A strategy of applying electrical stimulation to increase post-mortem muscle metabolism and hasten the onset of rigor mortis in other species (Hwang *et al.*, 2003) might improve the quality characteristics of camel meat. Troy and Tarrant (1987) found that electrically-stimulated beef muscles exhibited changes in electrophoretically–determined myofibrillar protein bands. Alteration of myofibrillar protein structure could possibly alter the myosin ATPase histochemical staining (Kadim *et al.*, 2009a,b).

Previous works showed that low voltage electrical stimulation improved meat quality characteristics of whole camel carcasses at different age groups (Kadim *et al.*, 2009a, b). However, the effect of low voltage electrical stimulation has not been studied on split carcasses of camels. Generally, splitting large carcasses is a common practice in slaughter house to reduce the space required for handling and storage. This study was designed to study the effect of low voltage electrical stimulation on biochemical and meat quality characteristics of the *Longissimus thoracis* muscle from unsplit or split longitudinally carcasses of one-humped camels slaughtered at 1-2 or 8-10 years of old.

2. Materials and methods

2.1. Animals, electrical stimulation and meat samples

Thirty camels representing two age groups (15 animals in each group): 1-2 and 8-10 year old groups were randomly assigned to four post-mortem treatment groups (5 replicates/group). Five carcasses from each age group were split into two halves in which electrical stimulation was applied to one side and the other side was used as a control (Table 1). The animals were slaughtered and dressed following routine commercial slaughterhouse procedures. Five carcasses from each age group were split longitudinally along the vertebral column, approximately 20 minutes post-mortem. Half of the unsplit and split carcasses were electrically-stimulated 30 minutes post-mortem. This gave a total of eight treatments as shown in Table 1. Electrical stimulation was performed using a V1.3-R3B stimulator (7.5 millisecond duration every 70 milliseconds (14 Hz) and an output of 90 V, AgResearch, New Zealand). Carcasses were stimulated for 60 seconds with a battery clip attached to the upper lip of the jaw and a stainless steel hook contacting the Achilles tendon. *Longissimus thoracis* samples from the left side of the carcasses were removed between the 10-13 ribs (800-1000 g) immediately after stimulation. Samples were transported in an insulated cool box to the meat science laboratory at Sultan Qaboos University, then transferred to a chiller (1-3^{o}C) within 3-4 hours post-mortem and kept for 24 hours before meat quality assessment was undertaken.

Table 1. Summary of carcasses split and electrically stimulated treatments used in the experiment and the number of animals in each treatment

Age	Carcass	Treatments	No. of replicates
1-2 years	Unsplit carcass	Electrically-stimulated	5 carcasses
	Unsplit carcass	Non-stimulated	5 carcasses
	Split carcass	Electrically-stimulated	5 sides
	Split carcass	Non-stimulated	5 sides
8-10 years	Unsplit carcass	Electrically-stimulated	5 carcasses
	Unsplit carcass	Non-stimulated	5 carcasses
	Split carcass	Electrically-stimulated	5 sides
	Split carcass	Non-stimulated	5 sides

2.2. Muscle pH decline

The pH of the *Longissimus thoracis* muscle from the left side of the carcass was monitored using a portable pH meter (Hanna waterproof pH meter, Model Hi 9025, Italy) fitted with a polypropylene spear-type gel electrode (Hanna Hi 1230) and a temperature adjusting probe. PH measurements were recorded at 40 minutes, and 1, 2, 4, 6, 8, 10 and 12 hours post-mortem.

2.3. Histochemistry

Muscle sectioning and staining used in the present study were described by Kadim *et al*. (2009a, b). Briefly, approximately 1 cm^3 core samples of *Longissimus thoracis* were removed immediately after electrical stimulation and frozen in liquid nitrogen. Sections 8µm thick were prepared on a cryostat and mounted on silane-treated microscope slides. Two sections were incubated in pH 4.35 and 4.60 for 10 minutes and then incubated in adenosine 5-triphosphate substrate (Brooke and Kaiser, 1970). Another section was incubated in a solution containing nitro blue tetrazolium stain (Sheehan and Hrapchak, 1989). Stained sections were viewed under an Olympus BX51 light microscope (Olympus, BXSITE, Tokyo, Japan) at a magnification of 40X. Images were taken using an Olympus DP70 camera. Five randomly areas of the staining section were selected to measure diameter and number of muscle fibres using Olympus BX51 light microscope.

2.4. Transmission electron microscopy

Fibres from *Longissimus thoracis* muscle were dissected and placed immediately in vials containing an electron microcopy fixative solution as described by Kadim *et al.* (2009a, b). Briefly, muscle fibers were fixed in 1% Osmium Tetraoxide for 60 minutes, then washed in three changes over 10 minutes in 1M cacodylate buffer to wash off excess Osmium Tetroxide. The muscle fibres were embedded in pure Araldite epoxy resin and polymerized overnight at 60^{o}C, then 0.5 µm sections were prepared, and stained with Toludine blue. Ultra thin sections (60-90 nm) were cut using a diamond knife and leica UCT ultra microtome, stained with aqeous urtanyl acetate and lead citrate and examined with a JEOL JEM-1230 transmission electron microscope equipped with a Gata 792-CCD camera operated at 60kV. Electron images of muscle fibre ultrastructures were recorded to find out any alteration in muscle structure caused by electrical stimulation.

2.5. Meat Quality Evaluation

The muscles were evaluated for a range of quality characteristics including ultimate muscle pH, expressed juice, percentage cooking loss, Warner-Bratzler shear force values, sarcomere length, myofibrillar fragmentation index (MFI) and colour *L**, *a**, *b** as described by Kadim *et al*. (2009a, b). Briefly, the ultimate pH was assessed in homogenates of duplicate 1.5-2 g of muscle tissue in 10 ml of neutralized 5-mM sodium iodoacetate and the pH of the slurry measured using a Metrohm pH meter. Chilled muscle samples (13 mm x 13 mm cross section) for assessment of shear force by a Warner-Bratzler device were prepared from muscle samples cooked in a water bath at 70^{o}C for 90 minutes. The same samples were used to calculate cooking loss (difference between weights of samples before and after cooking). Sarcomere length was determined using a laser diffraction procedure described by Cross *et al.* (1980/1981). Expressed juice was assessed using a filter paper method, as the total wetted area less the meat area (cm^2) relative to the weight of the sample (g). Myofibrillar fragmentation index (MFI) was measured using a modification of the method of Johnson *et*

al. (1990). The proportion of muscle fragments that passed through a 231-µm filter was measured. CIE *L*, a*, b** light reflectance coordinates of the muscle surface were measured using a Minolta Chroma Meter CR-300.

2.6. Statistical Analysis

The general liner model, ANOVA procedure within SAS (1993) was used to compare the effect of electrical stimulation and age group on muscle fibre type, meat quality characteristics of camel *Longissimus thoracis* muscles from unsplit and split carcasses. Significant differences between means were assessed using the least-significant-difference procedure. Interactions between electrical stimulation, splitting carcass and age group were excluded from the model when not significant (P>0.05).

3. Results and Discussion

Pronounced changes in carcass posture were observed during electrical stimulation including contraction of most of the external visible carcass muscles with the low voltage current, as well as bending of the back and rigid extension of the fore and hind limbs. This movement is an indication of muscle contraction which suggests the carcass is responding to the electrical stimulation. Similar observations have been reported on camel carcasses (Kadim *et al*., 2009a, b) and beef carcasses (Taylor and Marshall, 1980).

3.1. Kinetics of Decline pH

Average pH time curves for the *Longissimus thoracis* muscle from various treatments are presented in Figure 1. Changes in glycolysis from electrical stimulation were monitored by measuring the rate of pH fall after stimulation, and post-mortem time taken by muscles to reach a pH of 6.0. Rate of pH decline was significantly affected by electrical stimulation. Age group had no significant effect on the rate of pH decline, however there were differences in muscle pH decline rate between electrically-stimulated and non-stimulated groups within each age group at various times post-mortem. In agreement with the present study, Kadim *et al*. (2009b) used a similar breed of one-humped camel and found that camel age had no significant effect on the rate of pH decline. At 40 minutes post-mortem, the average pH values in the stimulated group were 0.22 and 0.25 units below the non-stimulated group for unsplit and split-carcasses, respectively. Moreover, electrical stimulation led to significantly lower muscle pH values during the first 6 hours post-mortem (Figure 1). Similar findings were reported by Kadim *et al.* (2009a, b). After a relatively fast fall within the first 6 hours, the mean pH values underwent a slow decline until an ultimate pH at 24 hours post-mortem. These findings are in accordance with those of Kadim *et al.*, (2009a, b) and Li *et al.* (2006) that electrical stimulation led to a fast decline in pH within the first 3-4 hours in meat from camels and beef.

The average difference in pH (1-6 hours post-mortem) between the electrically-stimulated and non-stimulated unsplit and split carcasses ranged between 0.24-0.25 and 0.18-0.22 units, respectively. pH values for the stimulated or non-stimulated *Longissimus thoracis* muscles for unsplit or split carcasses for the two age groups did not differ at any time post-mortem. The time needed for muscle pH values to reach 6.0, is a reflection of rigor onset. In non-electrically-stimulated muscles, the time to pH 6.0 ranged from 6.5 to 7.6 hours (Figure 1). Electrical stimulation at 30 minutes post-mortem reduced the time of muscle pH to reach 6.0 to an average of 3 hours. Reduction of the time required for muscles to reach pH 6.0 is of very practical importance since it determines the period of delay necessary

before muscle temperature can be dropped below 10°C if cold shortening of the carcass is to be avoided (Chrystall *et al.*, 1980).

Table 2. Mean and standard error of mean (SEM) for muscle fibre characteristics of *Longissimus thoracis* muscles from electrically-stimulated (ES) and non-stimulated (NS) unsplit or split carcasses of camels slaughtered at two age groups (1-2 and 8-10 years).

	Unsplit carcass				Split carcass					Significance[1]		
	1-2 years		8-10 years		1-2 years		8-10 years		SEM			
	ES	NS	ES	ES	NS	ES	NS	ES		C[2]	A[3]	ES
Proportion												
Type 1	31.0^{a}	31.5^{a}	24.9^{b}	24.7^{b}	31.7^{a}	32.1^{a}	24.2^{b}	24.1^{b}	1.056	-	*	-
Type IIA	36.5^{a}	37.0^{a}	40.0^{b}	39.8^{b}	36.3^{a}	36.3^{a}	39.6^{b}	39.0^{b}	1.517	-	*	-
Type IIB	32.5^{a}	31.5^{a}	35.1^{b}	35.5^{b}	33.0^{a}	31.6^{a}	36.2^{b}	36.9^{b}	1.001	-	*	-
Diameter µ												
Type 1	80.3^{a}	83.1^{a}	95.9^{b}	97.9^{b}	80.3^{a}	82.3^{a}	94.9^{b}	97.9^{b}	3.200	-	*	-
Type IIA	91.7^{a}	90.2^{a}	107.2^{b}	105.8^{b}	89.9^{a}	87.9^{a}	106.2^{b}	103.2^{b}	3.336	-	*	-
Type IIB	98.6^{aal}	96.1^{a}	113.3^{b}	109.3^{b}	97.4^{a}	95.9^{a}	110.9^{b}	108.3^{b}	4.678	-	*	-

[1]Significance: * P<0.05, Interactions between the electrical stimulation, carcass and age groups were excluded from the table because they were not significant. Means in the same row with different superscripts are significantly different. [2] C: carcass vs. side, [3] A: age (1-2 vs. 8-10). Interactions were not significant, so they are not shown.

Table 3. Mean and standard error of mean (SEM) for a range of meat quality characteristics of *Longissimus thoracis* muscles from electrically-stimulated (ES) and non-stimulated (NS) unsplit and split camel carcasses.

	Unsplit carcass				Split carcass					Significance[1]		
	1-2 years		8-10 years		1-2 years		8-10 years		SEM			
	ES	NS	ES	NS	ES	NS	ES	NS		C[2]	A[3]	ES
Ultimate pH	5.55^{a}	5.68^{b}	5.65^{a}	5.76^{b}	5.50^{a}	5.63^{b}	5.56^{a}	5.70^{b}	0.050	-	*	**
Expressed Juice	41.9^{bc}	38.1^{a}	40.8^{b}	37.4^{a}	42.8^{b}	38.5^{a}	40.2^{b}	37.1^{a}	1.38	-	-	*
Percentage cooking loss	26.6^{b}	23.4^{a}	26.8^{b}	22.0^{a}	26.5^{b}	23.2^{a}	25.1^{b}	22.0^{a}	1.25	-	-	*
Sarcomere length (µm)	1.81^{b}	1.66^{a}	1.79^{b}	1.60^{a}	1.85^{b}	1.68^{a}	1.80^{b}	1.63^{a}	0.047	-	-	**
Myofibrillar fragmentation index%	76.4^{C}	72.2^{b}	71.1^{b}	67.3^{a}	78.0^{c}	73.0^{b}	72.6^{b}	67.9^{a}	0.97	-	*	**
Shear force value (kg)	5.46^{a}	6.74^{b}	6.70^{b}	8.90^{c}	5.13^{a}	6.33^{b}	6.19^{ab}	8.22^{c}	0.178	-	**	**
Colour Lightness (*L**)	42.4^{bc}	39.1^{a}	40.5^{b}	38.1^{a}	44.1^{c}	40.9^{b}	40.9^{c}	38.5^{a}	1.21	-	**	**
Redness (*a**)	15.3^{a}	16.5^{ab}	15.6^{a}	17.6^{ab}	15.9^{a}	17.4^{ab}	17.3^{ab}	18.1^{b}	0.87	-	*	-
Yellowness (*b**)	5.61^{a}	5. 58^{a}	6.49^{b}	6.29^{b}	7.30^{b}	6.52^{b}	7.28^{b}	7.00^{b}	0.359	-	**	-

[1]Significance: * P<0.05, **P<0.01, Interactions between electrical stimulation, carcass and age groups were excluded from the table because they were not significant. Means in the same row with different superscripts are significantly different. [2] C: carcass vs. side, [3] A: age group (1-2 vs. 8-10). Interactions were not significant, so they are not shown.

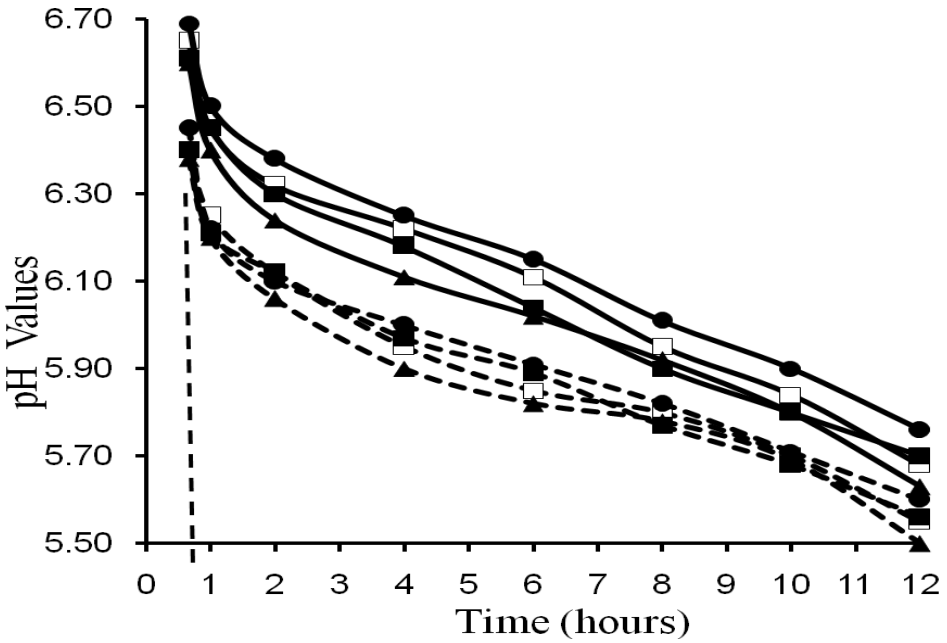

Figure 1. Mean changes in pH within the *Longissimus thoracis* muscle in carcasses from two age groups (1-2 and 8-10 years) and unsplit or split carcasses of camel, which were electrically-stimulated or non-stimulated (unsplit carcass (1-2 years): electrically-stimulated: --□--, or non-stimulated —□—, (8-10 years): electrically-stimulated: ---●--, non-stimulated: —●—, split carcass, split carcass (1-2 years): electrically-stimulated:--▲--, or non-stimulated: —▲—, (8-10 years): electrically-stimulated: --■--, or non-stimulated —■—).

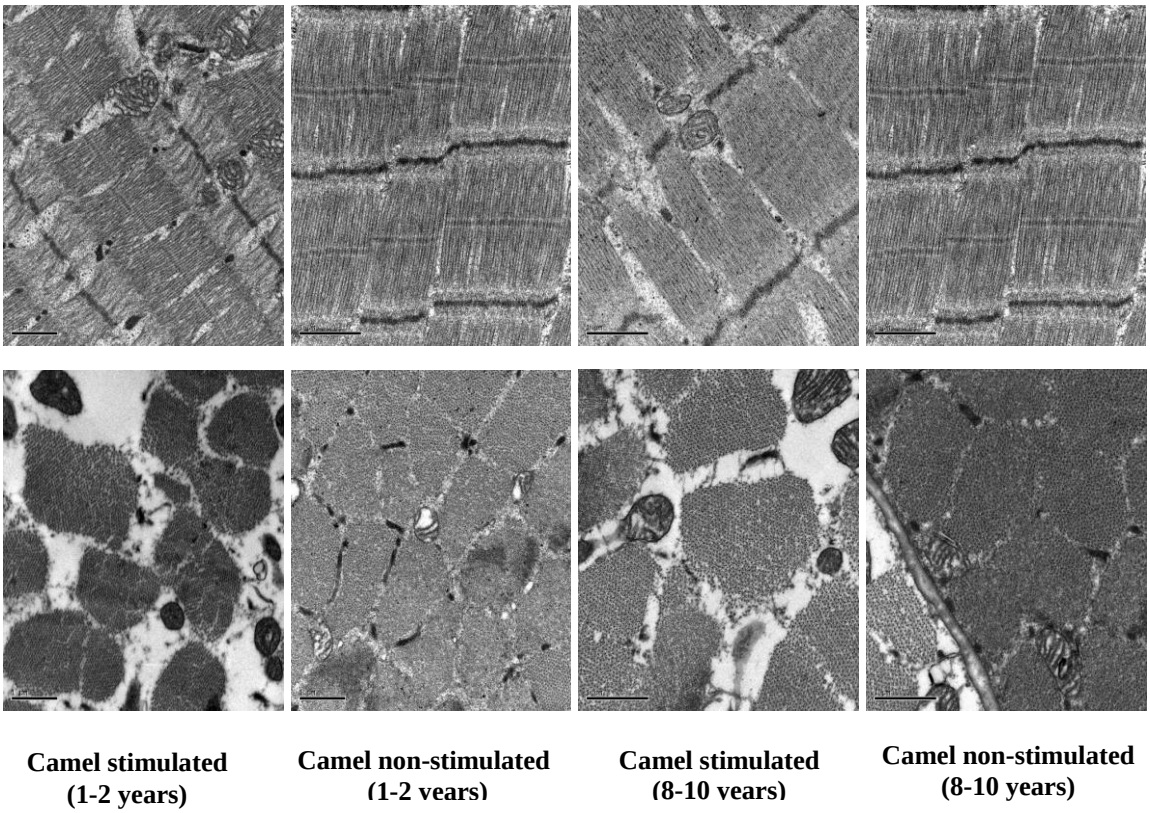

Figure 2. Micrograph from sections of electrically stimulated and non-stimulated sections of camel *Longissimus thoracis* muscle (magnification 30,000X) show pronounced transverse elements – the muscle fiber bundles are distorted and disintegrated and there are spaces between fibres and disintegration at inter fibrillar bridges.

3.2. Muscle Fiber Types

The distribution and diameters of the three myosin heavy chain isoproteins (Types I, IIA and IIB fibers) did not change as a result of either electrical stimulation or splitting carcasses (Table 2). In agreement with the present study, Kadim *et al.* (2009a, b), found that electrical stimulation had no significant influence on muscle fiber proportion. Although, there were small differences in the age range of camels between the present study and the previous study by Kadim *et al*. (2009b), the proportion of the three muscle fiber types between the two age groups was significantly different in both studies. *Longissimus thoracis* from 1-2 year-old camels had a significantly ($P<0.05$) higher proportion of Type I and a lower proportion of Type IIA and Type IIB muscle fibers than 8-10 year old animals (Table 2). A similar conclusion was reported in camels of ages between 2-3 and 10-12 years by Kadim *et al*. (2009b). Although, electrical stimulation and splitting of the carcass had no significant effect on muscle fiber diameter, the 8-12 year old camels had significantly larger fiber diameters than camels in the 1- 2 year age group. Kadim *et al.* (2009b) also found that 10-12 year-old camels had significantly larger fiber diameters than 2-3 year-old camels. Similarly, Spindler *et al*. (1980) showed that a muscle fiber diameter increases with age in camels.

3.3. Ultimate pH

There were significant ($P<0.05$) differences in ultimate pH (at 24 hours) between the electrically-stimulated (5.60 and 5.53) and non-stimulated (5.72 and 5.67) unsplit and split carcasses (Table 3). According to Watanabe *et al.* (1996), ultimate muscle pH is a major determinant of meat quality and is related to the rate of glycogen breakdown. Electrical stimulation does not improve meat quality unless it significantly accelerates post-mortem glycolysis (Dutson *et al.,* 1982). In the present study electrical stimulation increased early post-mortem glycolysis in unsplit and split carcass muscle samples evaluated (Figure 1). The ultimate pH value of the camel meat was within the normal range of other animals' meat (Shariatmadari and Kadivar, 2006: Kadim *et al.*, 2006, 2008a, b, 2009a, b). However, meat from 1-2 year old camels had slightly lower ultimate pH values (5.59) than 8-10 year old camels (5.67). The ultimate pH of meat is the result of a combination of several factors including pre-slaughter handling, post-mortem treatment, stored glycogen and muscle physiology (Ashmore *et al.,* 1973; Marsh, 1977; Thompson, 2002). The slight difference in ultimate pH between the two age groups in the present study might be due to differences in proportions of muscle fiber types (Table 2) or lower stores of muscle glycogen at the time of slaughter. Fibre types have different metabolic functions in the body (Ashmore *et al.,* 1972). Ashmore (1974) noted that Type I fibers have, in addition to high metabolic capacity for oxidative metabolism, a capacity for glycogenolytic metabolism that is not much lower than that of Type IIA fibers. The present study indicated that the higher proportion of fast-twitch fibers was related to low ultimate pH.

3.4. Shear Force Value

The mean Warner-Bratzler shear force values (kg) are given in Table 3. Carcass splitting had no significant effect ($P>0.05$) on the shear force values of the camel meat. However, muscles from unsplit and split electrically-stimulated carcasses had significantly ($P<0.05$) lower shear force values, 6.1 and 5.73 kg, compared to non-stimulated carcasses, 7.80 and 6.71 kg, respectively. The present results indicated that electrical stimulation improved meat tenderness by 20% via changes in post-mortem muscles by either physical disruption of the myofibrillar matrix (Figure 2) or the

acceleration of proteolysis (myofibrillar fragmentation index: Table 3) or by preventing cold-shortening (sarcomere length: Table 3). Histological images showed the appearance of contracture bands predominantly stretched as well as ill-defined and disrupted sarcomere (Figure 2). This implies that physical disruption per se lowers the resistance to mechanical shearing force. Similarly, other studies have found a relationship between physical disruption and improved tenderness for high (300-500 volts) (Will *et al.,* 1980; Takahashi *et al.*, 1987), for intermediate voltage (145-250 volts) (Ho *et al.,* 1996; Sorinmade *et al.*, 1982) and for low voltage (90 volt) systems (Kadim *et al.*, 2009a, b). Kadim *et al*. (2009a, b) observed improvements in tenderness of camel meat from electrically-stimulated carcasses. The main mechanism through which electrical stimulation improves tenderness is assumed to be by rapidly decreasing the concentration of ATP and reducing the likelihood of myofibrillar contraction and cold shortening (Davey and Gilbert, 1974). Savell *et al.* (1978) proposed that violent contractions from electrical stimulation might cause increased tenderness via muscle structural damage. Electrical stimulation in the present study revealed that carcasses responded to electrical stimulation much more violently when applied to the side after splitting than when applied to unsplit carcasses. However carcass splitting had no effect ($P>0.05$) on the shear force values of either stimulated or non-stimulated carcasses. These results indicate that it is not essential to enhance tenderness by splitting carcasses prior to electrical stimulation treatment. Similarly, McKeith *et al.* (1981) found that electrical stimulation improved tenderness of beef irrespective of splitting the carcass.

The *Longissimus thoracis* muscles from 8-10 year old camels had significantly higher shear force values (7.25 kg) than muscles (5.92 kg) from the 1-2 year old camels (Table 3). These results agree with previous findings that *Longissimus thoracis* muscles from 6-8 (Kadim *et al.,* 2006) and 10-12 year old camels (Kadim *et al*., 2009b) were tougher compared to 1-3 and 2-3 year-old camels, respectively. It is commonly accepted that younger animals yield more tender meat than older ones (Kadim et al., 2006). A number of studies have shown that shear force values increase with increase in age of the camel (Kadim *et al.,* 2006, 2008b, 2009b). Any differences due to age may be related to histological changes that may take place in muscle structure and composition as animals mature, particularly in the connective tissue (Asghar and Pearson, 1980). This suggests that the increase in shear force values for 8-12 year-old camels, in the present study, may be due to connective tissue structure and its heat stability (Bruce *et al.,* 2004). The high fragmentation index in 1-2 year old camels may be caused by easily breaking myofibrils into shorter segments, which led to a rupture of myofibrils during the 24 hours post-mortem.

3.5. Colour

Low voltage electrical stimulation tended to increase the CIE L^* and b^* and decrease a^* values which significantly ($P<0.05$) improved the lightness (L^*) of muscles (Table 3). Similarly, Kadim *et al.* (2009a, b), studying camels, and Riley *et al.* (1981) and King *et al.* (2004), studying beef, reported that lean meat from electrically stimulated carcasses, have a brighter red colour than lean meat from non-stimulated carcasses. Myoglobin concentration, pH and muscle fiber type influence the development of muscle colour (MacDougall and Rhodes, 1972; Faustman and Cassens, 1990). Post-mortem protein degradation is directly related to the ultimate pH, which increases light scattering properties of

meat and consequently increase *L**, *a** and *b** values (Offer, 1991). Meat samples from *Longissimus thoracis* muscles of 8-10 year old camels were darker (39.5 vs. 41.6 *L**), redder (17.2 vs. 16.3 *a**) and yellower (6.8 vs. 6.3 *b**) than that of meat samples from 1-2 year old camels (Table 3). These results are in agreement with values reported for camels by Kadim *et al.* (2009a, b). The camel meat in the present study had similar *L** values, relatively higher *a** values and lower *b** values than those reported by Shariatmadari and Kadivar (2006) for Iranian camels. This darker color is more likely a result of increased myoglobin content (Lawrie, 1979) due to age differences. Other factors causing this phenomenon include muscle fiber type (Faustman and Cassens, 1990; Abril *et al.*, 2001). Post-mortem protein degradation increases light scattering properties of meat and thereby increases the lightness value (Offer, 1991), which is also directly related to the pH (Abril *et al.*, 2001).

3.6. Expressed Juice

Splitting of the carcass longitudinally had no effect on expressed juice values (Tables 3). Filter paper wetness of electrically stimulated muscle samples were significantly higher ($P<0.05$) by 8.7% than non-stimulated samples as reported by Kadim *et al*. (2009a, b). This may be partly due to the presence of denatured sarcoplasmic proteins in the myofibrillar fraction (Eikelenboom and Smulders, 1986, Den Hertog-Meischke *et al.*, 1997). The lower expressed juice of electrically-stimulated muscles was probably due to differences in pH of the myofibrillar protein suspensions (Offer and Knight, 1988). Cooking loss followed the same pattern as expressed juice with electrically stimulated muscles having significantly higher ($P<0.05$) cooking loss than non-stimulated samples (Table 3). Expressed juice values were significantly ($P<0.05$) affected by the age of the camel, with 1-2 year-old camels having more expressed juice than 8-10 year-old animals (Tables 3). In agreement with the present study, Dawood (1995), Kadim and Mahgoub (2007), and Kadim *et al*. (2006, 2009b) found that meat from camels below 3 years of age had significantly higher expressed juice than meat from 6-12 year old camels. These differences were due to variations in fat content or in ultimate pH (Miller *et al.*, 1968; Abril *et al.*, 2001). The decreased binding ability of less mature animal meat, higher moisture content and a lower degree of marbling may contribute to the variations (Kadim et al., 2006).

3.7. Myofilbrillar Fragmentation Index

The myofibrillar fragmentation index was significantly ($P<0.05$) higher in electrically-stimulated than the non-stimulated carcasses in both age groups with no effect of splitting carcasses. Kadim *et al.* (2009a, b) found that electrical stimulation had a significant effect on myofibrillar fragmentation index of camel meat from *Longissimus thoracis* muscles. This may be attributed to either variation in muscle pH (Table 3) or to protein degradation as reflected in electronic microscopic images (Figure 2). Electrically-stimulated muscles exhibited faster protein degradation than non-stimulated muscles (Ho *et al.*, 1996). There is a strong relationship between physical disruptions of the myofibrillar degradation (Ho *et al.*, 1996; Thomson *et al.*, 1996; Nagaraj *et al.*, 2005). There were significant differences between the two age groups of camels in myofibrillar fragmentation index in the present study (Table 3). This may be due to the myofibrils breaking into shorter segments in 1-2 year old camels more than 8-10 year old camels.

4. Conclusion

Electrical stimulation had a significant effect on meat quality characteristics of camel meat. This was probably due to ultrstructural alteration as well as an increase in protein degradation. In view of the findings of the present study, low voltage electrical stimulation can be used to improve camel meat quality characteristics which are a useful improvement for a potential source of meat particularly in the arid tropics.

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