Trop Anim Health Prod (2011) 43:89–97
DOI 10.1007/s11250-010-9658-3

ORIGINAL RESEARCH

Growth, carcass yield and meat quality attributes of Red Maasai sheep fed wheat straw-based diets

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Accepted: 7 July 2010 / Published online: 18 July 2010

Abstract Thirty-two castrated Red Maasai sheep (12.7 kg initial body weight, aged 12–18 months), were used in an 84-day experiment to evaluate diets based on treated straw upon growth performance, carcass yield and meat quality. The animals were blocked by weight into four similar groups and randomly allotted into four dietary treatments, with eight individually fed animals per treatment. The dietary treatments were ad libitum untreated wheat straw (UTS), wheat straw treated with urea and lime (TS), straw and ad libitum hay (UTSH), and TS and ad libitum hay (TSH). In addition, each experimental animal received 220 g/day (on as fed basis) of a concentrate diet. Treatment of straw increased ($P<0.05$) dry matter intake (42.3 vs. 33.7 g/kgW^{75}/day), energy intake (4.6 vs. 3.7 MJ ME/d) and the average daily gain (40.7 vs. 23.1 g). Animals on TS produced heavier ($P<0.05$) carcasses (6.6 vs. 5.4 kg) with superior conformation than animals on UTS. Percentage cooking loss was higher in carcasses from animals fed TS compared to those from other diets. Except M. *longissimus dorsi* and M. *semitendinosus*, tenderness of muscles was not affected by diet but ageing of meat improved ($P<0.001$) tenderness. Overall, straw treatment increased carcass yields with limited effects on meat quality attributes.

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Keywords Crop residues · Sheep · Productivity · Meat quality

Introduction

During dry season, sheep in the tropical countries are largely dependent on crop residues and low-quality roughages. These diets, however, are low in protein and high in fibre which limit intake and digestibility (Buranov and Mazza 2008). High content of lignin and low accessibility of cell wall polysaccharides by both cell-free and microbial enzymes impede the utilisation of gross energy contained in fibrous roughages. Nonetheless, the nutritive value of crop residues can be improved by supplementation with other feedstuffs or by treatment with chemicals which increase digestibility and/or feed intake by partial solubilization of cell wall components hemi-cellulose and lignin as reviewed by Sundstøl and Owen (1984). Various techniques to improve utilisation of low-quality forages have been tested but the techniques have to a large extent not been adopted by farmers in tropical countries for various reasons including economic constraints (Ben Salem and Smith 2008). However, earlier studies (Trach 2000) reported that a combination of urea ($CO(NH_2)_2$) and lime ($CaO/Ca(OH)_2$) for chemical treatment of straw is more economically feasible although the effects of forage alkali treatments on animal performance are often variable due to the variation in the type/genotype of crop used and treatment conditions (Nurfeta et al. 2009). In addition, the efficiency at which low-quality roughages are digested depends on species of the animal (Li et al. 2008) and breed of animal within species (Habib et al. 2008). There is limited information on performance of the indigenous sheep in Tanzania in terms of growth rate, carcass characteristics and meat quality

when raised on upgraded crop residues. This study was therefore designed to evaluate the effects of using treated wheat straw alone or in combination with grass hay on growth performance, carcass characteristics and meat quality attributes of Red Maasai sheep.

Materials and methods

Animals and management

Thirty-two castrated sheep (12.7±0.29 kg initial body weight, aged 12–18 months), were used in the 84 days experiment which was preceded by an adaptation period of 14 days. The animals were purchased from farmers and transported to Magadu Research Farm, Sokoine University of Agriculture. On arrival at the farm, initial weights were recorded. The animals were distributed into four groups based on their initial body weight. Each group consisted of eight comparable animals which were then randomly assigned to one of the four dietary treatments in a completely randomised block design. All animals were injected with ivermectin (Kelamectin 1%) for treatment and control of gastro-intestinal and ecto-parasites. The animals were housed in individual pens.

Feeds and feeding

Wheat straws were chopped into about 5 cm long using a straw chopper and weighed in 10 kg lots. Using a digital weighing balance, 200 g of fertiliser-grade urea were weighed and dissolved in 10 litres of water to make a 2% solution which was sprayed over the 10 kg straws with a watering can. The straws were then mixed with 300 g of unslaked lime and placed in sealed plastic bags and stored for about 3 weeks before use. Hay was also chopped, and provided in separate troughs to animals receiving it. Each animal was offered experimental diets in two lots daily; at 8.00 and 14.00 h. Feeding was done on individual basis. The dietary treatments were ad libitum untreated wheat straw (UTS), wheat straw treated with urea and lime (TS), straw and ad libitum hay (UTSH), and TS and ad libitum hay (TSH). In addition, each experimental animal was offered 220 g of concentrate once daily. The concentrate was composed of maize bran (70%), sunflower seedcake (28%) and mineral mix (2%). The mineral mix consisted of (in %, manufacturer's specifications) Ca (25.8), S (0.3), Mg (0.5), Fe (0.1), Na (29.05), P (12.9), Cl (31.08), Zn (0.02), B-cr (0.02) and K (0.05). Grass hay consisting of *Bracharia and Bothriocloa* species and wheat straws were offered on ad libitum basis (20% refusal rate). Daily weights of feed offered and daily feed refusals were recorded to derive daily feed intake.

Body weight measurements and slaughter procedures

All animals were weighed weekly during the adaptation and experimental periods. At the end of the growth trial, the final weight of each animal was obtained by averaging live weights recorded for two consecutive days. Growth rate (g/day) was calculated as the (final body weight (BW) (g)−initial BW (g))/number of days on trial. Feed conversion ratio was calculated as the amount of feed consumed (kg DM) per body weight gain (kg).

At the end of the 12 weeks of feeding trial, feed was withheld overnight and the animals were weighed to record the shrunk body weight (SBW). The animals were then slaughtered following standard procedures described by Colomer-Rocher et al. (1987). After slaughter, the head was removed at the atlanto–occipital joint and fore and hind feet removed at the carpus–metacarpal and tarsus–metatarsal joints, respectively (Garcia-Valverde et al. 2008). Hot carcass weights (HCW) were recorded immediately after slaughter then the carcasses were split into two halves through the median plane using a hand saw. Non-carcass components which included skin, head, feet, heart, lungs, trachea, liver, and kidney were weighed and recorded. Digestive tract was weighed while full and when empty. The weight of digestive contents was computed as the difference between full and empty digestive tract. Empty body weight (EBW) was computed as the difference between SBW and the weight of digestive content. Commercial dressing percentage was expressed as hot carcass weight (HCW)×100/SBW and true dressing percentage as cold carcass weight (CCW)×100/EBW. Internal carcass length (CL), measured from lumbo-sacral joint to the cervico-thoracic joint was used to determine carcass compactness (CCW/CL).

Assessment of carcass conformation and fatness scores was based on EUROP classification system (Johansen et al. 2006). Carcasses were classified for conformation (scale from E=excellent (5) to P=poor (1) and fatness (scale from 1=none or low fat cover to 5=entire carcass covered with fat) based on visual scores. Each of the five classes for conformation and fatness were divided into three sub-classes: −, 0, or +, to form 15 grades. Grade 1 is P- for conformation and 1- for fatness. Grade 15 is E+ for conformation class and 5+ for fat class.

Temperature and pH measurements

Temperature and pH of the carcasses were measured 45 min and 6 h post-mortem (PM), at the same point on the M.

gluteobiceps of the right half-carcasses. An electrode (Mettler Toledo) of a portable pH-meter (Knick-portamess 910, Germany) was inserted at the geometrical centre of the muscle. The carcasses were then chilled at 0°C overnight. The ultimate pH (pHu) and temperature were recorded on the same muscle 24 h PM. Both the right and left chilled carcasses were reweighed to obtain cold carcass weights (CCW).

Muscle sampling and tissue separation

For determination of cooking losses and Warner–Bratzler shear force (WBSF), 10 muscles were sampled from the left half of the carcass of each animal, 24 h PM. The muscles were *Longissimus dorsi*, *Gluteobiceps*, *Infraspinatus*, *Supraspinatus*, *Psoas major*, *Rectus abdominis*, *Semimembranosus*, *Semitendinosus*, *Triceps brachii* and *Vastus lateralis*. The muscles were weighed to obtain initial weight (W1) and vacuum packed in PVC bags using a vacuum packing machine (Komet plus Vac 20, Germany). Three samples of LD muscle each measuring approx. 7 cm long were prepared from each animal to study effects of conditioning on meat tenderness. One LD sample was immediately frozen at -25°C while the other LD muscle samples were conditioned in a fridge set at 4°C for 6 or 9 days before also being frozen at −25°C. These conditioning treatments are referred to as LD (0 d), LD (6 d) and LD (9 d) in this paper. The remaining parts of the left half-carcasses were dissected into muscle, fat and bone for estimation of carcass composition. Total weight of muscles included weights of the ten individual muscles sampled at 24 h PM. Thereafter, muscle and fat tissues from the left half-carcasses were homogenised, mixed and three sub-samples taken for chemical analysis.

Cooking loss determination

The ten muscles were thawed at 4°C overnight before analyses. The muscles in the water-tight PVC bags were then boiled in a thermostatically controlled water bath (Fisher Scientific, Pittsburgh, PA) set at 70.5°C for a total of 50 min. The boiled muscles were left to equilibrate with the room temperature for 2 h, and then transferred to a refrigerator set at 4°C for 12 h. The muscles were removed from the PVC bags and blotted dry by paper towel and weighed (W2). Cooking loss was computed as ((W1−W2)/W1)×100.

Determination of shear force values

The samples for the determination of cooking loss were also used to determine meat tenderness. The muscles were cut into 1×1×1 cm cubes. Muscle toughness (shear force) was measured as the maximum force (N/cm^2) required for shearing through the cubes perpendicular to the muscle grain, at a crosshead speed of 100 mm/min using a Warner–Bratzler shear force blade, fitted to Zwick/Roell (Z2.5, Germany) instrument. The average peak shear force for six cubes per muscle sample was considered as a force needed to shear through a particular muscle.

Chemical analyses of feed samples

Samples of feeds used in dietary treatments were dried (70°C), ground (1 mm screen) and stored for subsequent analyses of dry matter (DM), crude protein (CP), ether extract, ash, neutral detergent fibre (NDF), acid detergent fibre (ADF), crude fibre, in vitro dry matter and organic matter digestibility. DM, N and total ash were determined according to the official methods of AOAC (2000) and NDF and ADF according to Van Soest et al. (1991). Ash content was determined by ashing at 600°C for 6 h. Nitrogen was determined by Kjeldahl method (CP=N×6.25). In vitro dry matter digestibility and in vitro organic matter digestibility were determined according to Tilley and Terry (1963). Metabolisable energy content of concentrate diet was estimated using the equation of MAFF (1975): $\mathrm{ME\,(MJ/kgDM)} = 0.012\,\mathrm{CP} + 0.031\,\mathrm{EE} + 0.005\,\mathrm{CF} + 0.014\,\mathrm{NFE}$. For other diets, the equations of AFRC (1993) were used to estimate the ME contents as follows: Hay ME=2.67+0.0110 DOMD; untreated wheat straws ME=0.53+0.0142 DOMD and treated wheat straws ME=2.24+0.0098 DOMD.

For the meat samples, water content was determined by the weight loss of 3 g minced meat and LD samples dried for 48 h in 104°C oven according to AOAC (2000). Similarly, ash content was determined by ashing the dried samples in a 600°C muffle furnace for 6 h. Total lipid content (g fat/100 g sample) was estimated in 5 g samples after a 6-cycle extraction with petroleum ether in a Soxhlet apparatus. Crude protein content was determined using 1 g sample following the Kjeldahl method as described in the AOAC (2000).

Statistical analysis

Data were analysed using the GLM procedures of SAS (2001). Dietary treatments were considered as fixed effects whilst residuals were considered as random effects. Each individual animal served as an experimental unit for all the parameters assessed. Covariance analysis, with initial live weight as a covariate, was used to correct for the various traits studied. In all analyses, when least squares means

were different at $P<0.05$, they were separated by the PDIFF option of SAS.

Results

Growth, feed intake and yield of carcasses and non-carcass components

Urea and CaO treatment increased the CP content of wheat straw from 40 to 55 g/kg DM (Table 1). There was a slight decrease in NDF content from 756 to 732 g/kg DM while ADF increased from 448 to 484 g/kg DM. Metabolisable energy in wheat straws increased by 39% as a result of chemical treatment. Higher growth rates were recorded in animals on treated wheat straw (TS, TSH) compared with those on untreated wheat straw (UTS, UTSH)-based diets (Table 2). Diet caused significant differences on mean final body weight (FBW), shrunk body weight (SBW), empty body weight (EBW) and carcass weight (Table 3). These were heavier for animals fed TS than those fed UTS based diets. The gut fill of animals fed UTS tended ($P<0.1$) to be larger than that of animals on TS whilst the commercial dressing percentage was higher ($P<0.05$) for TS than UTS fed animals. Results in Table 4 show that diets affected ($P<0.05$) hot carcass weight (HCW). The lowest values were recorded for animals fed UTS. Furthermore, carcasses from TS had higher ($P<0.05$) conformation and fatness scores than those from UTS. Mean conformation score was O^- based on 15-point scale. Neither straw treatment nor hay inclusion influenced the linear carcass measurements.

Carcass composition and meat quality attributes

The weight of muscles from animals on treated straw-based diets was higher ($P<0.05$) compared with those fed untreated straw-based diets (Table 5). Diets, however, had no ($P>0.05$) effect on dissectible muscle contents in sheep when expressed as percentage of carcass weight. The percentage of fat tissue in the carcasses from sheep fed TS, TSH and UTSH were similar ($P>0.05$) but higher ($P<0.05$) than that recorded in the carcasses from UTS. The dietary treatments did not ($P>0.05$) affect pH values for M. g*luteobiceps* (Table 6). However, minced meat from animals on UTS contained higher ($P<0.05$) proportions of moisture, protein and ash compared to other diets. The variations in proximate composition were nonetheless not clearly associated with the effect of straw treatment. Except for M. g*luteobiceps* and M. *triceps brachii*, diet had no effect on the cooking loss of most of the individual muscles studied but wide variations were observed in cooking losses between muscles (Table 7). The cooking loss for *M. semimembranosus* was about twice as great as that of M. *rectus abdominis*. With exception of M. *longissimus dorsi* (0 d) and M. *semitendinosus*, WBSF values were not affected by diet (Table 8). There were differences ($P<0.01$) on pooled values for cooking loss with higher losses from animals fed treated straw-based diets (Table 9). The losses decreased ($P<0.05$) with increasing ageing time with day 6 and 9 having significantly lower loss than 0 d ageing. Post-mortem ageing of sheep meat improved ($P<0.001$) tenderness especially after 9 days of ageing. The WBSF value of LD 9 days was 20% lower than that of LD 0 days.

Table 1 Chemical composition of the experimental feeds

Chemical composition	Feedstuff			
	Concentrate	TS	UTS	Hay
Dry matter (g/kg)	910	580	890	900
Crude protein (g/kg DM)	173	55	40	39
Ether extract (g/kg DM)	134	12	16	12
Ash (g/kg DM)	52	98	106	87
Neutral detergent fibre (g/kg DM)	391	732	756	737
Acid detergent fibre (g/kg DM)	223	484	448	429
Crude fibre (g/kg DM)	146	334	340	353
In vitro dry matter digestibility (g/kg DM)	546	590	360	396
In vitro organic matter digestibility(g/kg DM)	546	570	360	310
Nitrogen free extract	405	81	388	409
Metabolisable energy (MJ/kg DM)	12.6	7.83	5.64	6.08

Table 2 Least squares means±SE for intake and growth performance of castrated Red Maasai sheep fed different diets

Variable	Diets					
	UTS	TS	UTSH	TSH	SE	Sign.
Intake (g DM/day)						
Straw	146^{bc}	243^{a}	77^{d}	124.5^{c}	12.3	***
Hay	–	–	138^{b}	159.5^{a}	4.1	***
Conc.	211	219	211	211	0.7	–
Total	358^{d}	463.9^{b}	427^{c}	495.9^{a}	13.5	***
Intake (% BW)	2.36^{c}	2.81^{ab}	2.66^{b}	2.89^{a}	0.1	***
Intake g/kgW$^{.75}$/day	33.7^{c}	42.3^{a}	39.4^{b}	44.7^{a}	0.9	***
Energy intake (MJ, ME/day)	3.48^{c}	4.61^{a}	4.00^{b}	4.65^{a}	2.4	***
Daily gain (g/day)	23.1^{c}	40.7^{ab}	34.1^{bc}	47.8^{a}	2.6	***
Total gain (kg)	1.96^{c}	3.51^{ab}	2.89^{bc}	4.08^{a}	0.3	***
FCR (kg DMI/kg gain)	15.6	11.2	13.1	10.4	2.4	****
BCS (1–5)	2.5	2.9	2.9	3.4	1.5	NS

Least squares means with a common superscript in the same row are not significantly different ($P>0.05$)

NS not significant, *SE* standard error of mean, *UTS* untreated straw, *TS* treated straw, *UTSH* untreated straw with hay, *TSH* treated straw with hay, *FCR* feed consumed (kg) for 1 kg body weight gain, *BCS* body condition score

*$P<0.05$; **$P<0.01$; ***$P<0.001$; ****$0.05<P<0.1$

Table 3 Least squares means±SE for final body weight (FBW), slaughter weight (SBW), fasting loss, empty BW, gut fill, dressing percentage and individual organs as the proportion (%) of shrunk weight of castrated Red Maasai sheep fed different diets

Variable	Diets					
	UTS	TS	UTSH	TSH	SE	Sign.
FBW (kg)	14.9^{c}	15.9^{ab}	15.8^{bc}	16.7^{a}	0.2	**
SBW (kg)	14.5^{c}	15.7^{a}	15.1^{b}	16.3^{a}	0.2	**
Empty BW (kg)	11.4^{b}	12.6^{a}	12.1^{b}	13.7^{a}	0.3	*
Gut fill % Live weight	20.4	18.9	19.7	18.8	1.9	NS
Gut fill % Empty BW	28.1	25.3	25.2	26.6	2.4	NS
Commercial dressing %	33.25^{b}	43.97^{a}	41.90^{a}	41.58^{a}	1.2	**
True dressing %	42.50^{c}	52.77^{a}	49.35^{ab}	47.27^{b}	1.1	***
Individual organs % of shrunk weight						
Blood	4.21	4.41	4.13	3.41	0.3	NS
Spleen	0.20	0.21	0.23	0.21	0.0	NS
Liver	1.33	1.26	1.38	1.30	0.1	NS
Heart	0.52	0.57	0.58	0.51	0.0	NS
Kidneys	0.30	0.33	0.28	0.27	0.0	NS
GI tract (empty)	6.94	9.54	7.53	6.84	1.4	NS
GI tract (full)	26.9	25.4	29.0	26.9	1.9	****
Lung, trachea and diaphragm	1.26	1.47	1.53	1.56	0.1	NS
Head, skin and feet	18.31	16.76	15.88	20.18	1.4	NS
Total non-carcass yield	33.13	34.56	31.50	34.29	2.4	NS

Least squares means with a common superscript in the same row are not significantly different ($P>0.05$)

NS not significant, *SE* standard error of mean, *UTS* untreated straw, *TS* treated straw, *UTSH* untreated straw with hay, *TSH* treated straw with hay. *Shrunk weight* live weight of animals after 16 h of fasting

*$P<0.05$; **$P<0.01$; ***$P<0.001$; ****$0.05<P<0.1$

Table 4 Least squares means±SE of hot carcass weight (HCW), EUROP classification and linear carcass measurements of castrated Red Maasai sheep fed different diets

Variable	Diets					
	UTS	TS	UTSH	TSH	SE	Sign.
HCW (kg)	5.4[b]	6.6[a]	6.3[a]	6.7[a]	0.3	*
Score (1–15) conformation	2.5[c]	4.1[ab]	4.1[ab]	4.8[a]	0.5	**
Score (1–15) fatness	1.5[b]	2.0[b]	1.8[b]	4.0[a]	0.8	*
Carcass measurements (cm)						
Carcass length	44.9	46.8	39.6	47.0	2.2	NS
Chest depth	20.7	21.7	20.8	20.9	1.3	NS
Hind- limb length	31.6	32.4	31.5	31.7	0.6	NS
Hind-limb width	54.0[b]	56.3[a]	54.0[b]	56.0[a]	0.6	*
Compactness index (g/cm)	133	154	135	159	35	NS

Least squares means with a common superscript in the same row are not significantly different ($P>0.05$)

NS not significant, *SE* standard error of mean, *UTS* untreated straw, *TS* treated straw, *UTSH* untreated straw with hay, *TSH* treated straw with hay

*$P<0.05$; **$P<0.01$; ***$P<0.001$; ***$0.05<P<0.1$

Discussion

Feed intake, yield of carcasses and non-carcass components

The improvement in CP content by chemical treatment of wheat straw in the present study is similar to an increase of 37.5% (26 vs. 42 g/kg DM) reported by Nurfeta et al. (2009) but lower than that of Sharma et al. (2004) who recorded more than a twofold increase (39 vs. 85 g/kg DM). Probable reasons for these variations include differences in treatment conditions and the initial straw quality. Higher DMI in sheep fed TS-based diets is presumably attributed to the increase in dietary protein which might have caused increased rate and extent of fibre digestion in the rumen. In addition, the increase in ME of straws as a result of chemical treatment may explain the observed higher weight gains recorded in sheep fed treated wheat straw-based diets.

Based on the EUROP grading system for conformation and fatness estimates, the findings indicate that besides sustaining sheep in the dry season, straw treatment has a potential to produce carcasses of fair conformation and fatness. The observed variation in fat content in the carcasses may have resulted from differences in dietary energy intake which were 4.61, 4.65, 3.48 and 4.00 MJ, ME/day for the animals on TS, TSH, UTS and UTSH, respectively. Feeding regimen affects carcass composition

Table 5 Least-squares means±SE for weights, percentage and ratios of carcass tissues from castrated Red Maasai sheep fed different diets

Variable	Diets					
	UTS	TS	UTSH	TSH	SE	Sign.
Muscle (kg)	3.00[b]	3.66[a]	3.40[b]	3.78[a]	0.1	***
% carcass wt	64.60	64.71	64.17	64.61	1.3	NS
% SLW	6.47	7.32	7.18	6.31	0.5	****
Fat (kg)	0.40[c]	0.70[ab]	0.62[bc]	0.56[c]	0.1	**
% carcass wt	8.9[b]	12.3[a]	11.5[ab]	11,8.0[a]	1.3	*
% SLW	1.41[b]	2.59[a]	2.09[ab]	1.54[b]	0.3	***
Bone (kg)	1.2	1.3	1.28	1.36	0.0	NS
% carcass wt	26.3[a]	22.96[b]	24.03[ab]	23.5[b]	1.1	**
% SLW	4.26	4.51	4.28	4.09	0.3	NS
Muscle: fat	8.44	5.64	5.88	6.10	0.9	NS
Muscle: bone	2.46	2.81	2.67	3.15	0.3	NS

Least squares means with a common superscript in the same row are not significantly different ($P>0.05$)

NS not significant, *SE* standard error of mean, *UTS* untreated straw, *TS* treated straw, *UTSH* untreated straw with hay, *TSH* treated straw with hay

*$P<0.05$; **$P<0.01$; ***$P<0.001$; ****$0.05<P<0.1$

Table 6 Least-squares means±SE for pH and temperature of *M. gluteobiceps* and chemical composition of minced meat from castrated Red Maasai Sheep fed different diets

Variable	Diets					
	UTS	TS	UTSH	TSH	SE	Sign.
pH 45 min	6.41	6.12	6.49	6.44	0.1	NS
pH 24 h	5.75	5.72	5.72	5.76	0.3	NS
Temp, °C (45 min)	32.1^{ab}	32.1^{ab}	32.2^{b}	32.9^{a}	0.8	*
Temp, °C (24 h)	5.0	5.0	4.9	4.3	0.6	NS
Moisture (%)	68.5^{a}	63.4^{b}	64.1^{b}	63.4^{b}	1.0	*
Protein (%)	19.9^{a}	17.6^{b}	18.2^{b}	18.7^{ab}	0.4	*
Fat (%)	5.4^{c}	11.8^{a}	8.6^{b}	9.7^{ab}	2.0	*
Ash (%)	5.8^{a}	4.5^{b}	4.7^{b}	4.9^{ab}	0.3	*

Least squares means with a common superscript in the same row are not significantly different ($P>0.05$)

NS not significant, *SE* standard error of mean, *UTS* untreated straw, *TS* treated straw, *UTSH* untreated straw with hay, *TSH* treated straw with hay

*$P<0.05$; **$P<0.01$; ***$P<0.001$; ****$0.05<P<0.1$

of farm animals particularly the fat content when there is variation in energy concentration and intake of diets (Mushi et al. 2009).

Meat quality attributes

The average ultimate pH (pHu) of 5.7 for sheep after completion of glycolysis (24 h PM) in the present study is within the quality range of pHu<6.0 (Miranda-de la Lama et al. 2009). The rate of pH fall and the ultimate pH (pHu) are important determinants of meat quality and are related to the rate of glycogen breakdown (Abdullah and Qudsieh 2009). Elevated pH affects several meat characteristics including modifications of membranes and extracellular fluids, which affect the meat's electrical properties (Damez and Clerjon 2008). The lack of dietary effect on pH values in the present study agrees with the observation made on Assaf lambs fed ad libitum commercial concentrates and barley straw or whole grain and protein supplement (Rodríguez et al. 2008) but contrasts those of Olfaz et al. (2005) where differences in pH were recorded due to greater glycogen concentrations in Karayaka growing rams fed high energy diets compared with lambs on low energy diet. In the present study, however, it could be argued that

Table 7 Least squares means±SE for the cooking loss (%) of muscles from castrated Red Maasai Sheep fed different diets

Muscle	Diets					
	UTS	TS	UTSH	TSH	SE	Sign.
LD(0 d)	29.8	32.7	33.4	34.7	1.2	NS
LD(6 d)	22.8	30.3	25.9	29.8	1.3	NS
LD(9 d)	26.9	29.8	25.8	32.0	1.2	NS
Gluteobiceps	30.6^{c}	41.9^{a}	31.7^{bc}	29.8^{c}	1.3	*
Infraspinatus	20.6	28.8	26.8	26.5	1.3	NS
Psoas major	27.9	29.6	32.9	27.2	1.2	NS
Rectus abdominis	21.6	18.4	13.3	18.8	1.4	NS
Semimembranosus	32.4	39.0	35.8	38.7	1.3	NS
Semitendinosus	23.6	30.1	30.2	27.3	1.3	NS
Supraspinatus	34.4	37.4	37.2	40.7	1.3	NS
Triceps brachii	26.6^{b}	36.1^{a}	26.1^{b}	31.8^{ab}	1.2	*
Vastus lateralis	30.3	35.1	32.3	33.4	1.3	NS

Least squares means with a common superscript in the same row are not significantly different ($P>0.05$)

NS not significant, *SE* standard error of mean, *UTS* untreated straw, *TS* treated straw, *UTSH* untreated straw with hay, *TSH* treated straw with hay. *LD (0d)*, *LD (6d)* and *LD (9d)* M. *longissimus dorsi* aged for 0, 6 and 9 days, respectively

*$P<0.05$; **$P<0.01$; ***$P<0.001$

Table 8 Least squares means±SE for Warner–Bratzler shear force values (*N*) of muscles from castrated Red Maasai Sheep fed different diets

Muscle	Diets					
	UTS	TS	UTSH	TSH	SE	Sign.
LD(0 d)	17.2	24.6	16.9	19.5	1.1	****
LD(6 d)	14.7	15.0	15.7	16.9	1.2	NS
LD(9 d)	13.3	14.6	15.1	14.0	1.2	NS
Gluteobiceps	23.7	29.6	25.4	24.7	1.2	NS
Infraspinatus	17.6	15.8	16.2	17.1	1.2	NS
Psoas major	18.0	15.5	15.3	20.5	1.1	NS
Semimembranosus	28.7	29.5	22.0	28.4	1.2	NS
Semitendinosus	21.7	22.9	15.3	20.9	1.1	****
Supraspinatus	26.8	23.1	23.5	23.6	1.2	NS
Triceps brachii	20.6	18.0	19.6	18.2	1.2	NS
Vastus lateralis	20.3	22.0	18.3	19.1	1.1	NS

NS not significant, *SE* standard error of mean, *UTS* untreated straw, *TS* treated straw, *UTSH* untreated straw with hay, *TSH* treated straw with hay. *LD (0d)*, *LD (6d)* and *LD (9d)* M. *longissimus dorsi* aged for 0, 6 and 9 days, respectively

*$P<0.05$; **$P<0.01$; ***$P<0.001$; ****$0.05<P<0.1$

differences in energy content between diets were not large enough to elicit significant differences in pH values.

The rate of temperature fall post-mortem affects tenderisation since this process is dependent on post-mortem proteolysis mediated by proteolytic enzymes such as calpains and lysosomal proteases (Kemp et al. 2010). Muscle temperature falling below 15°C with pH higher than 6.0–6.4 during early post-mortem, causes shortening of muscle to occur thereby limiting tenderness through reduction of calpain activity and ageing potential (Kannan et al. 2006). The temperature and pH decline in the present study suggest that conditions were unfavourable for muscle shortening to occur. The observed variation in cooking loss with ageing time could be attributed to increased volume of myofibrils in aged meat, which leads to higher water holding capacity (Kolczak et al. 2007). Ageing increases tenderisation by weakening the structural integrity of the myofibrilar proteins (Han et al. 2009), and the rate of tenderisation varies with ageing time. Findings from 9 days of ageing in the present study are comparable with those of Abdullah and Qudsieh (2009) where ageing meat from Awassi ram lambs for 7 days reduced the shear force by 26% (from 28.3 N in day 1 to 20.7 N in day 7). A review by Warriss (2004) indicated that up to 80% of 'maximum' tenderness of sheep meat could be reached in 7.7 days of ageing. Generally, muscles studied in the present study were tender as the values were below 52.7 N above which meat is considered tough (Destefanis et al. 2008).

Conclusion

Treatment of wheat straw with urea/lime solution increased dry matter and energy intake in sheep which resulted in improved live weight gain and carcass conformation. Straw

Table 9 Least squares means±SE for pooled cooking loss (%) and Warner–Bratzler shear force values (*N*) for castrated Red Maasai Sheep by dietary treatments and duration of ageing

Variable	Cooking loss (%)	Shear force (*N*)
Treatment		
TS	32.3^{a}±0.9	20.9±0.8
TSH	30.9^{ab}±0.9	20.5±0.8
UTS	27.9^{c}±0.9	20.5±0.9
UTSH	29.3^{bc}±0.9	18.1±0.9
Significance	**	****
Ageing		
LD (0d)	32.6^{a}±1.3	19.6^{a}±0.8
LD (6d)	27.7^{b}±1.4	15.7^{ab}±0.9
LD (9d)	28.4^{b}±1.4	14.4^{c}±0.9
Significance	*	***

Least squares means with different superscripts in the same column are significantly different. *NS* not significant, *SE* standard error of mean, *UTS* untreated straw, *TS* treated straw, *UTSH* untreated straw with hay, *TSH* treated straw with hay. *LD (0d)*, *LD (6d)* and *LD (9d)* M. *longissimus dorsi* aged for 0, 6 and 9 days, respectively

*$P<0.05$; **$P<0.01$; ***$P<0.001$; ****$0.05<P<0.1$

treatment, however, had limited effects on meat quality attributes. Investigation on the economics and practical aspects of this technology at farmers' level is recommended.

Acknowledgements The authors wish to thank the financial support from the Norwegian Agency for Development Co-operation through SUA-PANTIL project of Sokoine University of Agriculture.

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