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Effects of concentrate levels on fattening performance, carcass and meat quality attributes of Small East African × Norwegian crossbred goats fed low quality grass hay

D.E. Mushi [a,b,*], J. Safari [a,d], L.A. Mtenga [c], G.C. Kifaro [c], L.O. Eik [a]

[a] Department of Animal and Aquacultural Sciences, Norwegian University of Life Sciences, P.O. Box 5025, N-1432 Ås, Norway
[b] Department of Life Sciences, Mkwawa University College of Education, Private Bag, Iringa, Tanzania
[c] Department of Animal Science and Production, Sokoine University of Agriculture, P.O Box 3004, Morogoro, Tanzania
[d] Institute of Rural Development and Planning, P O Box 138, Dodoma Tanzania

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ABSTRACT

To assess the effects of finishing Small East African × Norwegian crossbred goats with concentrate diets on the fattening performance, carcass and meat quality, 32 castrated crossbred goats (9.5 months old, 17.1 kg BWT) were equally allocated into four levels of concentrate supplementation. The concentrate levels were: Zero access to concentrate (T0), 33% access to ad libitum concentrate allowance (T33), 66% access to ad libitum concentrate allowance (T66) and 100% access to ad libitum concentrate allowance (T100). Each animal had access to ad libitum grass hay. Ad libitum concentrate intake for the goats was 663 g/d, which supported ME intake of 8.7 MJ/head/d. The attained maximum daily gain was 96 g/d. T100 and T66 goats were comparable in slaughter weight but the former had 2 kg heavier ($P<0.05$) carcasses than the latter. T100 and T66 goats were similar in carcass fatness scores, though both were fattier ($P<0.05$) than other diet groups. Dressing percentage (DP) was expressed in three different ways. In all but commercial DP, T100 were comparable to T66 goats, but all were higher than the other diet groups. For T0 goats, pH-values remained above 6 even after 24 h post-mortem. Cooking losses increased ($P<0.05$) with increasing levels of concentrate supplementation. Moreover, among the muscles assessed, *M. rectus abdominis* had the least cooking loss. Warner–Bratzler shear force values of cooked muscles were highest ($P<0.05$) in *M. gluteobiceps*, followed by *M. vastus lateralis*, while *M. psoas major* and *longismus dorsi* aged for 6 days had the least values. Finishing Small East African × Norwegian crossbred goats at 66% access to their *ad libitum* concentrate intake gives optimum carcass and meat quality, and that any increase above this level seems not to improve meat production.

1. Introduction

The economic importance of goats especially for smallholders in developing countries as a source of animal protein and income is on increase (Atti et al., 2004; Mahgoub et al., 2005). In Tanzania, Small East African goats (SEA), the main goat breed, are kept mainly for meat production. However, the productivity of these goats is still low, attaining a market weight of 20 kg at 2 years of age (Mushi, 2004). Moreover, these animals produce poor quality meat, mainly of low tenderness. This situation has caused lack of prime prices for locally produced meat, especially in niche markets. Despite the large population of goats in Tanzania (13.1 million), large amount of chilled and frozen meat products are imported into the country. The major causes of low production levels of local goats under traditional systems are poor nutrition and

* Corresponding author. Department of Animal and Aquacultural Sciences, Norwegian University of Life Sciences, P.O. Box 5025, N-1432 Ås, Norway. Tel.: +47 64965182; fax: +47 64965101.
E-mail addresses: daniel.mushi@umb.no, danielmushi@yahoo.com (D.E. Mushi).

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genotype. These animals are mainly raised and finished on poor quality range pastures.

Growing animals on concentrate-based diets generally have higher average daily gain, dressing percentage and carcass quality than those on pasture (Priolo et al., 2002; Kosum et al., 2003). Moreover, adjusting energy levels in a diet in order to produce high quality goat carcasses could be beneficial to goat producers, especially if they satisfy consumer desire by altering carcass composition and the quality of meat (Abdullah and Musallam, 2007). However, attempts to finish SEA goats on higher plane of nutrition showed limited improvement with respect to carcass gain and meat tenderness (Safari et al. *in preparation*). It can thus be hypothesized that in order to obtain better quality products, crossbreeding SEA goats with improved breeds is desirable. In Tanzania, Norwegian dairy goats were introduced in 1980s, such that crosses of SEA and Norwegian dairy goats are in relatively big numbers (Safari et al., 2005). The available F1 male crosses are not used for breeding purposes and could be used for meat production. Nonetheless, there is limited published information on the feasibility of feedlotting such goat crosses to improve their carcass yield and meat quality. Further investigation on the carcass and meat attribute of SEA × Norwegian crossbred goats finished under intensive management is needed to evaluate their future role in meat production in Tanzania. This study therefore seeks to determine carcass yield and meat physicochemical properties of castrated SEA × Norwegian crossbred goats (F1) finished under different levels of concentrate supplementation.

2. Materials and methods

2.1. Animals and treatments

Thirty-two castrated Small East African × Norwegian crossbred goats (9.5 ± 0.5 months old, 17.1 ± 1.2 kg BWT), were bought from Mulbadaw Farm in the Northern part of Tanzania. The animals were transported to the Department of Animal Science farm, Sokoine University of Agriculture, for the study. Goats were castrated 2 weeks after birth using a burdizo.

Goats were then divided into 8 weight blocks and assigned at random, within blocks, to one of four dietary treatments. Dietary treatments were T0 where no concentrate supplementation was offered and T33 and T66 where amount of concentrate on offer consisted 33% and 66%, respectively of ad libitum concentrate intake (as fed basis). The fourth treatment, T100, involved feeding concentrate ad libitum allowing 10% refusal rate. Grass hay, as a basal diet, was offered ad libitum to each goat. Goats were group-fed whereby a group of four goats under the same dietary treatment were maintained in a 3.7 m × 29.3 m pen, for a total of 8 goats per dietary treatment.

2.2. Feeding management and kid growth

Animals were given a three-week adaptation period during which they were group-fed with access to ad libitum amount of hay and 150 g of concentrate feed per goat per day. Animals were treated against internal and external parasites using Ivermectin during this period. The experiment started on 20th September 2007 and lasted for 90 days. For both hay and concentrate, goats were fed twice daily and water was available ad libitum. Amount of both hay and concentrate on offer and refusals were weighed daily to derive feed intake. Goats were weighed weekly, before offered the morning feed. Live weight gain was calculated as a difference between initial and final live weight over specified intervals.

2.3. Measurements at slaughter

Animals were weighed in two consecutive days before slaughter to obtain final live weight (FLW), fasted for about 16 h and weighed again to get the slaughter live weight (SLW). All goats were slaughtered according to Islamic tradition, Halal, on the same property where they were raised. The head was removed at the atlanto-occipital joint and fore and hind feet removed at the carpal and tarsal joints, respectively. Gut fill was calculated as the difference between the weights of full and empty digestive tract. Empty body weight (EBW) was computed as the difference between slaughter weight and gut fill.

Carcasses (with kidneys, kidney and pelvic fat) were weighed immediately after slaughter to get hot carcass weight (HCW), and were scored for conformation and fatness based on EUROP classification system for goats (Kosum et al., 2003; Johansen et al., 2006). Carcasses were classified for conformation (scale from E = excellent to P = poor and fatness (scale from 1 = none or low fat cover to 5 = entire carcass covered with fat) according to the visual scores in the EUROP system. Each of the five classes for conformation and five classes for fatness were divided into three subclasses: −, 0, or +, to form 15 grades. Grade 1 is P− for conformation class and 1− for fat class. Grade 15 is E+ for conformation class and 5+ for fat class. High value for conformation class indicates a carcass with well to excellent rounded muscles. High value on fat class indicates a carcass with a high degree of external fat (subcutaneous).

2.4. Measurements on carcasses

Carcasses were dissected into two halves through the median plane using a band saw. The weights of half-carcasses were recorded. Temperature and pH of the carcasses were measured 45 min and 6 h post-mortem (PM), at the same point on the *M. gluteobiceps* from the right half-carcasses. A penetrating electrode (Mettler Toledo) of a portable pH-meter (Knick-portamess 910, Germany) was inserted at the geometrical centre of the muscle. The choice of the muscle based on its massive nature and the incision (for pH and temperature probes) not being detrimental to the carcass value. Carcasses were then chilled at 0 °C overnight. Ultimate pH (pHu) and temperature were recorded on the same muscle in the right half-carcasses at 24 h PM.

After chilling the carcasses overnight, the weights of right half-carcasses were recorded and doubled to obtain cold carcass weights (CCW). Cold carcass weights were used with the data obtained previously to calculate abattoir dressing percentages and chilling losses. Chilling loss was calculated as the weight lost after chilling the right half-carcasses at 0 °C for 24 h. Various linear measurements were taken on the cold right half-carcasses to determine carcass conformation:

internal carcass length (CL, from the lumbo-sacral joint to the cervico-thoracic joint), carcass depth (CD, from the dorsal to the ventral edges of the carcass side along the 9th rib) and hind leg length (LL, from the ridge of the distal end of the tibia to the cut edge of the subcutaneous fat along a line joining the anterior pubic symphysis) (Moran and Wood, 1986). Internal carcass length was used to determine carcass compactness (CCW / CL).

2.5. Muscle sampling for cooking loss and WBSF analyses

Ten muscles: *Semimembranosus*, *Semitendinosus*, *Gluteobiceps*, *Vastus lateralis*, *Rectus abdominis*, *Longismuss dorsi*, *Psoas major*, *Supraspinatus*, *Infraspinatus* and *Triceps brachii* were excised from the left half of carcasses, 6 h PM. Further, M. longissmus dorsi (LD) was split into 5 blocks measuring approx. 7 cm long. From anterior end of LD, the first three blocks were used for 0, 6 and 9 days ageing, respectively. The remaining two blocks, from the middle to the posterior end of LD, were prepared for proximate and fatty acid analyses. All the muscle samples (including LD muscle blocks) were weighed and packed in PVC bags (W1) before being stored in a fridge set at 4 °C overnight. Except for LD muscle samples, all other muscle samples were moved into a freezer set at −25 °C after an overnight-chilling in the fridge (i.e. 24 h post-mortem) till further analyses. For LD muscle, samples for 0 day ageing were moved into the freezer after 6 h post-mortem, whereas samples for 6 and 9 days ageing remained in the fridge for further 6 and 9 days, respectively, before being moved into the freezer.

The remaining parts of the left half-carcasses were chilled at 0 °C overnight after which they were dissected into muscle, fat and bone for estimation of carcass composition. Total weight of muscles included weights of the 10 muscles sampled at 6 h PM. Thereafter, muscle and fat tissues were thoroughly mixed together, minced (5 mm sieve) and three sub-samples taken for chemical analyses.

2.6. Cooking loss and Warner–Bratzler shear force (WBSF)

The ten muscles were thawed at 4 °C overnight before analyses. The muscles, in the water-tight PVC bags, were heated in a thermostatically controlled water bath (Fisher Scientific, Pittsburgh, PA) set at 70.5 °C for a total of 50 min. The heated 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 PVC bags, blotted dry with paper towel and weighed (W2). Cooking loss was calculated as $((W1-W2)/W1)\times 100$. A minimum of six cubes measuring $1\times1\times1$ cm, 2 cm long were prepared from each muscle for WBSF assessment. Preparation of each cube was done in such a way that muscle fiber direction was parallel to the cube length. Warner–Bratzler shear blade, with a triangular slot cutting edge, attached to Zwick/Roell (Z2.5, German) instrument was used to determine force (N/cm^2) required to shear through a muscle cube at right angle to the muscle fiber direction. The Zwick was set with 1 kN load cell, with a crosshead speed of 100 mm/min. The average shear force for 6 to 10 cubes per muscle sample was considered as a peak force for a particular muscle.

Table 1
Physical and chemical composition of concentrate, and chemical composition of grass hay used by goats.

	Feeds	
	Concentrate	Grass hay
Ingredients (g/kg DM)		
Maize bran	700	–
Sunflower seed cake	280	–
Lime (calcium carbonate)	13	–
Salt	2	–
Mineral premix	5	–
Components (g/kg DM)		
Dry matter	921.9	834.5
Organic matter	920.5	902.0
Crude protein	162.2	32.8
Ether extract	133.6	12.0
Crude fiber	145.8	353.3
Neutral detergent fiber	472.1	830.5
Acid detergent fiber	156.1	473.5
Ash	50.9	98.0
Nitrogen free extract	429.4	338.4
In vitro dry matter digestibility	545.6	395.5
In vitro organic matter digestibility	546.4	416.5
Metabolisable energy (MJ/kg DM)	13.4	9.2

2.7. Physical compositions of dietary feeds, chemical composition of dietary feeds, minced meat and LD samples

The grass hay consisted of *Bracharia* spp (70%) and *Bothriocloa* spp (30%). Chemical and fiber compositions of both the grass hay and concentrate were analysed according to AOAC (2000) and Van soest et al. (1991), respectively. The composition and nutritive value of diets used in the present study are shown in Table 1. Metabolisable energy contents of feeds were estimated from their chemical composition following the equation of MAFF (1975): ME (MJ/kg DM) = 0.012 CP + 0.031 EE + 0.005 CF + 0.014 NFE.

Water content was determined by weight loss of 3 g minced meat and LD samples dried for 48 h in a 104 °C oven according to AOAC (2000). Ash content was determined by further 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 a 1 g sample following the Kjeldahl method as described in the AOAC (2000).

2.8. Statistical analysis

Experimental data were analysed using the General Linear Model of SAS (2001). Dietary treatments were considered as fixed effects and residual as random effect. Except for the feed intake, each individual animal served as an experimental unit for all the variables assessed. Due to small variation in age of animals within treatments, all traits were corrected by animal age as a covariate. Further, in analysis of cooking loss, weights of raw muscle samples served as covariates. Analyses of WBSF data included both dietary treatment, muscle type and their interaction as fixed effects. However, dietary treatment × muscle type interaction was not significant; hence only effects of the main factors are reported and discussed in the present study. In

Table 2
Live weights, weight gains, feed and nutrient intakes, feed to gain ratio, fasting loss, empty body weight and condition scores of crossbred goats under different levels of concentrate supplementation.

Variable	Treatments			
	T0	T33	T66	T100
Initial age (months)	9.1 ± 0.5	9.6 ± 0.5	9.8 ± 0.5	9.5 ± 0.5
Live weights (kg)				
Initial	17.3 ± 1.2	16.7 ± 1.2	16.8 ± 1.2	17.4 ± 1.2
Final	16.1 ± 1.2^{c}	20.2 ± 1.1^{b}	23.9 ± 1.1^{a}	26.6 ± 1.1^{a}
Slaughter[1]	14.9 ± 1.1^{c}	18.9 ± 1.1^{b}	22.5 ± 1.1^{a}	25.3 ± 1.1^{a}
Gains				
Total (kg)	−2.2 ± 0.5^{d}	3.5 ± 0.5^{c}	6.7 ± 0.5^{b}	8.6 ± 0.5^{a}
Daily (g/)	−24.6 ± 5.8^{d}	38.5 ± 5.4^{c}	74.5 ± 5.4^{b}	95.7 ± 5.4^{a}
Intakes				
Concentrate (g/d)	0	250.0	500.0	662.5
Hay (g/d)	409.2	316.0	128.1	62.7
Total dry matter, g/d	341.5	494.2	568.0	663.1
Dry matter (% live weight)	2.3	2.8	2.8	2.6
Total energy (MJ/d)	3.1	5.5	7.2	8.7
Total crude protein (g/d)	11.2	46.0	78.3	100.8
FCR (kg DMI/kg weight gain)	− 14.0	12.8	7.6	6.9
Fasting loss (%)	7.4 ± 0.7	6.7 ± 0.7	5.9 ± 0.7	5.1 ± 0.7
Empty body weight, EBW (kg)	11.0 ± 1.0^{d}	15.1 ± 1.0^{c}	19.4 ± 1.0^{b}	22.3 ± 1.0^{a}
Body condition score (1–5)	1.3 ± 0.2^{d}	2.4 ± 0.2^{c}	3.6 ± 0.2^{b}	4.3 ± 0.2^{a}

[1]After 16 h of fasting. ^{a,b,c,d}Least square means in the same row lacking a common letter differ. T0, T33, T66 and T100 refer to zero, 33%, 66% and 100% access to ad libitum concentrate allowance, respectively. FCR is feed conversion ratio.

all analyses, when means were significant by ANOVA at $P<0.05$, they were separated by Least Significant Difference test.

3. Results

3.1. Diet intake and kid growth

The ad libitum concentrate intake for Small East African × Norwegian crossbred goats (T100) was 663 g/d, which was 413 g and 163 g higher than concentrate intake by goats with 33% (T33) and 66% (T66) access to ad libitum concentrate allowance, respectively (Table 2). On the other hand, T100 goats consumed 347 g, 253 g and 65 g lower grass hay than T0, T33 and T66 goats, respectively. Overall, total daily dry matter intake (g/d) ranged from 342 through 663, equivalent to 2.3 to 2.8% inclusive of animals' live weights. Consequently, energy intake for T100 goats (8.7 MJ/d) was 181%, 58% and 21% higher than that of T0, T33 and T66 goats, respectively. Similarly, protein intake for T100 goats (101 g CP/d) was nine-fold and two-fold higher than that of T0 and T33, respectively.

Though initial weights of animals between treatments were similar, their final weights differed (Table 2). Goats maintained entirely on grass hay (T0) generally experienced weight loss while goats on ad libitum access to concentrate allowance (T100) attained a final body weight of 27 kg, which was equivalent to a body weight gain of 9 kg for the experimental period (Table 2). Although similar to T66, the final weight for T100 goats was 11 kg and 6 kg heavier ($P<0.05$) than that of T0 and T33 goats, respectively. On the other hand, average daily body weight gain for T100 goats was 57 g and 21 g higher ($P<0.05$) than that of T33 and T66 goats, respectively (Table 2). Efficiency of feed utilisation (FCR) improved with level of concentrate supplementation: T100 goats were about two-fold more efficient than T33 goats. T100 and T66 goats were scored "fat" (4 units), T33 "thin" (2 units) and T0 "very thin" (1 unit).

3.2. Killing-out characteristics

Though T100 and T66 goats were comparable in slaughter weight (Table 2), T100 goats had 2 kg and 3 kg heavier ($P<0.05$) carcass weight and empty body weight (EBW) respectively than T66 goats. Hot carcasses from T100 goats were 56% and 17% heavier ($P<0.05$) than that from T33 and T66 animals, respectively (Table 3). T100 goats displayed higher EUROP scores for conformation (U — very good) and carcass compactness (212 g/cm) than animals in other diet groups. T100 goats scored 2, 5 and 8 units higher ($P<0.05$) than T66, T33 and T0 goats, respectively with respect to conformation. Similarly, T100 displayed 25, 66 and 115 g/cm higher compactness than T66, T33 and T0 goats, respectively. On the other hand, T100 and T66 goats were comparable (9-average to 10 — high) based on EUROP scores for fatness, but both were about 5 and 8 units higher ($P<0.05$) than T33 and T0 animals, respectively.

Dressing percentages (DP) for carcasses, expressed in three different ways, ranged from 33% through 57% (Table 3). In all but commercial dressing percentage, T100 had DP values comparable ($P>0.05$) to T66 goats, which were all higher than that for T33 and T0 goats. Chilling losses decreased with increasing carcass weights: carcasses from T0 goats had higher ($P<0.05$) losses than that of concentrate supplemented goats, which were all comparable. Consequently, a variation displayed in hot carcass weight among dietary groups was similar to that observed in cold carcass weight.

Table 3
Killing out characteristics of castrated crossbred goats under different levels of concentrate supplementation.

Variable	Treatments			
	T0	T33	T66	T100
Carcass weights (kg)				
Hot (HCW)	5.6 ± 0.6^{d}	8.2 ± 0.5^{c}	10.9 ± 0.5^{b}	12.8 ± 0.5^{a}
Cold (CCW)	5.0 ± 0.5^{d}	7.6 ± 0.5^{c}	10.1 ± 0.5^{b}	11.7 ± 0.5^{a}
EUROP grading (1–15 points)				
Conformation	2.0 ± 0.5^{d}	4.2 ± 0.5^{c}	7.3 ± 0.5^{b}	9.5 ± 0.5^{a}
Fatness	1.3 ± 0.6^{c}	5.1 ± 0.5^{b}	9.1 ± 0.5^{a}	10.1 ± 0.5^{a}
Linear cold carcass measurements (cm)				
Carcass length	50.5 ± 0.9^{c}	51.4 ± 0.9^{bc}	54.0 ± 0.9^{a}	54.9 ± 0.9^{a}
Chest depth	21.0 ± 0.5^{c}	22.3 ± 0.4^{b}	22.9 ± 0.4^{b}	24.2 ± 0.4^{a}
Hind leg length	35.0 ± 1.1	35.2 ± 1.0	35.4 ± 1.0	37.9 ± 1.0
Hind leg circumference	23.4 ± 1.0^{c}	30.2 ± 1.0^{b}	33.4 ± 1.0^{a}	34.2 ± 1.0^{a}
Dressing percentages (%)				
TD	51.3 ± 0.7^{c}	54.1 ± 0.7^{b}	56.4 ± 0.7^{a}	57.3 ± 0.7^{a}
AD	33.0 ± 0.7^{c}	40.0 ± 0.7^{b}	44.9 ± 0.7^{a}	46.3 ± 0.7^{a}
CD	37.0 ± 0.6^{d}	43.4 ± 0.6^{c}	48.6 ± 0.6^{b}	50.6 ± 0.6^{a}
Carcass compactness (g/cm)	96.7 ± 7.6^{d}	145.6 ± 7.1^{c}	186.4 ± 7.1^{b}	211.8 ± 7.1^{a}
Chilling loss (%)	7.9 ± 0.5^{a}	4.3 ± 0.5^{b}	3.6 ± 0.5^{b}	3.9 ± 0.5^{b}

^{a,b,c,d}Least square means in the same row lacking a common letter differ. T0, T33, T66 and T100 refer to zero, 33%, 66% and 100% access to ad libitum concentrate allowance, respectively. EBW is empty body weight. TD is true dressing (HCW × 100 / EBW); AD is abattoir dressing (CCW × 100 / SLW); CD is commercial dressing (HCW × 100 / SLW).

3.3. Carcass physical and chemical compositions

As expected, concentrate supplemented goats had higher ($P<0.05$) amount (kg) of fat in their carcasses than the un-supplemented ones, when determined physically (Table 4). However, T100 and T66 animals were similar ($P>0.05$) with respect to this variable, but both were fattier ($P<0.05$) than T33 and T0. On the other hand, proportions (%) of muscles in carcasses were similar for all the concentrate supplemented goats. Although proportion of bone did not vary greatly in carcasses from supplemented goats, the un-supplemented goats had higher proportion of this tissue compared to goats in other diet groups.

Increasing concentrate supplementation decreased ($P<0.05$) content of carcass water and ash and increased that of carcass chemical fat, without affecting that of protein (Table 4). Although fat content in T100 goat carcasses was comparable to that of T66 goats, both were1.5- to 2-fold higher than that of T33 and 7 to 8-folds higher than that of T0 goat carcasses. *M. longismus dorsi* (LD) is the most commonly used muscle for meat quality analysis. Increasing level of concentrate supplementation somewhat decreased ($P<0.05$) contents of moisture and increased that of fat without affecting content of protein and ash in LD samples.

3.4. Muscle physico-chemical properties

Decline in carcass pH-values was faster in the first 6 h PM while the decline more-or-less levelled off afterwards (Fig. 1). Moreover, the decline was faster ($P<0.05$) in concentrate supplemented goats than the un-supplemented ones. The pH-value for T100 animals after 45 min PM was equivalent to that of T0 goats after 6 h PM. Further, pH-values for T66 and T100 were below 6 after 6 h PM while values for T0 goats remained above 6 even after 24 h PM. On the other hand, carcass temperature for T0 animals was lower ($P<0.05$) at both 45 min and 6 h PM than that of concentrate supplemented goats, which were comparable (Fig. 2). However, goat carcasses from different levels of concentrate supplementation had similar temperature after 24 h.

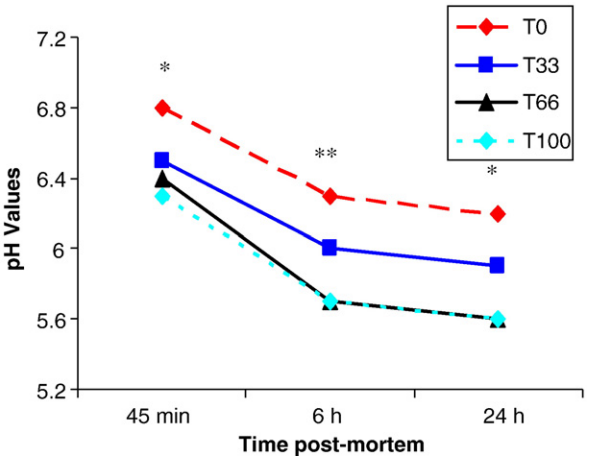

Fig. 1. pH decline post-mortem for carcasses from castrated crossbred goats under different levels of concentrate supplementation * and ** = $P<0.05$ and 0.01, respectively.

Cooking losses increased ($P<0.05$) with increasing levels of concentrate supplementation (Table 5). However, all the supplemented goats had comparable cooking losses, although T100 goats had numerically, but not statistically, the highest losses. The shear force value tended ($0.05<P<0.1$) to be reduced but only by 7–10% with increasing levels of concentrate supplementation. There were significant differences among muscles with respect to cooking losses and Warner–Bratzler shear forces (WBSF). *M. supraspinatus, M. semimembranosus* and *Vastus lateralis* had the highest ($P<0.05$) cooking losses while *M. rectus* abdominis had the least value. For the aged LD samples, the ranking order for cooking loss was: LD-0D>LD-9D = LD-6D. M. gluteobiceps

Table 4
Carcass physical and chemical, and *M. longismus dorsi* (LD) chemical compositions for castrated crossbred goats under different levels of concentrate supplementation.

Variable	Treatments			
	T0	T33	T66	T100
Carcass tissue weights (kg)				
Muscle	1.5 ± 0.2^{d}	2.4 ± 0.2^{c}	3.1 ± 0.2^{b}	3.7 ± 0.2^{a}
Fat	0.1 ± 0.1^{c}	0.1 ± 0.1^{b}	0.9 ± 0.1^{a}	0.9 ± 0.1^{a}
Bone	0.9 ± 0.1^{b}	0.8 ± 0.1^{b}	0.9 ± 0.1^{ab}	1.0 ± 0.1^{a}
Carcass physical composition[1] (%)				
Muscle	60.3 ± 1.2^{b}	65.2 ± 1.2^{a}	63.1 ± 1.2^{ab}	65.1 ± 1.2^{a}
Fat	2.7 ± 0.8^{c}	11.8 ± 0.8^{b}	17.6 ± 0.8^{a}	16.7 ± 0.8^{a}
Bone	37.1 ± 1.4^{a}	23.0 ± 1.4^{b}	19.3 ± 1.4^{bc}	18.1 ± 1.4^{c}
Carcass chemical composition (%)				
Moisture	74.8 ± 0.7^{a}	66.2 ± 0.7^{b}	63.1 ± 0.7^{c}	60.4 ± 0.7^{d}
Protein	21.8 ± 0.5^{a}	19.5 ± 0.4^{b}	19.0 ± 0.4^{b}	19.1 ± 0.4^{b}
Fat	1.7 ± 1.0^{c}	9.3 ± 1.0^{b}	14.2 ± 1.0^{a}	16.6 ± 1.0^{a}
Ash	4.4 ± 0.2^{a}	2.7 ± 0.2^{b}	2.0 ± 0.2^{c}	2.2 ± 0.2^{bc}
LD chemical composition (%)				
Moisture	76.6 ± 0.5^{a}	74.1 ± 0.5^{b}	73.3 ± 0.5^{b}	72.9 ± 0.5^{b}
Protein	24.0 ± 0.7	24.1 ± 0.7	22.5 ± 0.7	23.0 ± 0.7
Fat	0.1 ± 0.1^{c}	0.4 ± 0.1^{bc}	0.8 ± 0.1^{a}	0.6 ± 0.1^{ab}
Ash	2.4 ± 0.3	2.3 ± 0.3	2.5 ± 0.3	2.6 ± 0.3

[1]Percentage of total carcass tissue weight. [a,b,c,d]Least square means in the same row lacking a common letter differ. T0, T33, T66 and T100 refer to zero, 33%, 66% and 100% access to ad libitum concentrate allowance, respectively.

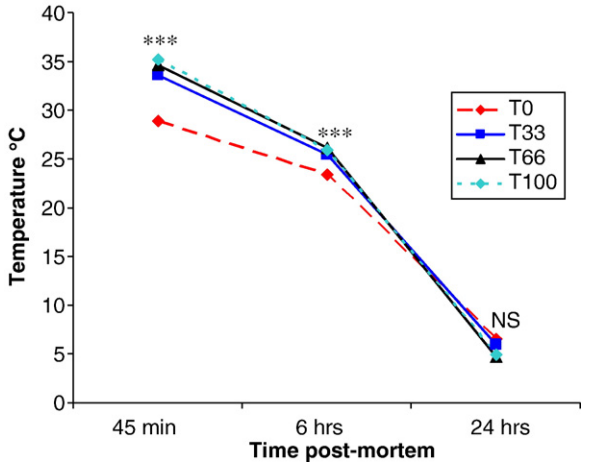

Fig. 2. Temperature decline post-mortem for carcasses from castrated crossbred goats under different levels of concentrate supplementation *** = $P<0.001$, NS = not significant.

Table 5
Cooking loss and Warner–Bratzler shear force values by treatments and muscles of castrated crossbred goats under different levels of concentrate supplementation.

	Variable	
	Cooking loss (%)	Shear force (N)
Treatment		
T0	22.4 ± 0.6^{b}	52.4 ± 1.7
T33	24.3 ± 0.5^{a}	50.7 ± 1.5
T66	24.4 ± 0.5^{a}	48.4 ± 1.4
T100	25.0 ± 0.5^{a}	47.0 ± 1.4
Muscles		
Triceps brachii	25.9 ± 0.9^{b}	53.4 ± 2.5^{cd}
Infraspinatus	21.1 ± 0.8^{f}	32.5 ± 2.4^{g}
Supraspinatus	29.8 ± 0.8^{a}	47.3 ± 2.4^{de}
LD-0D[1]	26.0 ± 0.9^{bc}	51.1 ± 2.8^{d}
LD-6D[2]	22.3 ± 0.9^{e}	36.6 ± 2.5^{fg}
LD-9D[3]	22.1 ± 0.9^{ef}	44.7 ± 2.5^{e}
Psoas major	23.3 ± 0.9^{de}	31.7 ± 2.4^{g}
Rectus abdominis	9.6 ± 0.8^{g}	NA
Semimembranosus	29.3 ± 0.9^{a}	64.7 ± 2.4^{b}
Semitendinosus	24.8 ± 0.8^{cd}	44.4 ± 2.4^{e}
Vastus lateralis	28.5 ± 1.1^{ab}	66.5 ± 2.5^{ab}
Gluteobiceps	25.3 ± 0.8^{c}	73.2 ± 2.4^{a}
Significance		
Treatment (T)	*	†
Muscles (M)	***	***
T*M	NS	NS

T0, T33, T66 and T100 refer to zero, 33%, 66% and 100% access to ad libitum concentrate allowance, respectively. [1,2,3]*M. longismus dorsi* aged for zero, six and 9 days respectively. [a,b,c,d,e,f,g]Least square means in the same column lacking a common letter differ. * and *** = $P<0.05$ and 0.001, respectively. †=$P<0.1$. NS = not significant. NA = not analysed.

had the highest ($P<0.05$) values for WBSF, followed by *M. vastus lateralis* and *M. semimembranosus*. On the other hand, M. Psoas major, infraspinatus, and longismus dorsi-6D had the least values for WBSF. Shear force values for cooked LD muscle decreased ($P<0.05$) with ageing in a curvilinear fashion, with the least value after six days of ageing. Overall, M. Psoas major, longismus dorsi-6D, infraspinatus, longismus dorsi-9D, semitendinosus and supraspinatus had WBSF values below 50 N while the rest were above that value.

4. Discussion

4.1. Diet intake and kid growth

In the present study, daily total dry matter intake (DMI) increased with level of concentrate supplementation; reached a maximum of 663 g/d in ad libitum fed goats. The findings from the present study differ from that of Lu and Potchoiba (1990) that DMI decreased in a curvilinear fashion as dietary energy density increased. The authors argued that ME intake rather than physical fill had overriding influence on DMI. In the present study energy concentration in both hay and concentrate remained the same throughout, what differed was the amount of concentrate accessible to individuals per day. Apparently, concentrate supplementation reduced forage intake but increased total dry matter intake in the present study. Overall, daily total energy intake for T0 and T33 goats (3.1 and 5.5 MJ ME) was below the recommended value of 5.78 MJ ME to attain a gain of at least 100 g/d (Langston University, 2000). Similarly, daily total crude protein intake for T0 and T33 goats (11.2 and 46 g/d) was below the recommended value (78 g/d) for attaining the above mentioned gain. The deficit in energy intake, in particular, might have caused a modification in body composition due to either fat loss or a sharp drop in body fat accumulation, with consequent proportional increase in lean flesh.

Growth rate increased when proportion of concentrate in the diet increased. Faster growth rates displayed by T66 and T100 goats may be chiefly attributed to increased DM, ME and CP intake throughout the experimental period. Mahgoub et al. (2000) and Santos-Silva et al. (2002) reported similar results. The observed maximum daily gain (96 g/d) in the present study with castrated Small East African × Norwegian crossbred goats on ad libitum access to concentrate intake is twice as high as that displayed by castrated indigenous Small East African goats (Safari et al. in preparation); though the two studies were independent. The achieved improvement in daily gain in crosses explains why crossbreeding of SEA goats with improved breeds is necessary for achieving improved growth performance. A higher gain could probably be achieved with intact bucks, which are known to grow faster than castrates (Mahgoub et al., 2005). The choice of castrates in the present study aimed to avoid objectionable male odour in meat from mature intact bucks.

4.2. Killing out characteristics

The observed higher empty body weights (EBW) and carcass weight for T100 than T66 goats, despite their similar slaughter weight, reflects higher GIT content in goats with higher intake of fibrous feeds (T66) than that with higher intake of concentrate (T100). Consequently, T100 goats had superior values for commercial dressing percentage over T66 goats. For T66 goats to have a productive performance equivalent to that of T100, T66 goats must have handled more bulky feed at any one time to compensate for the difference in both dry matter and energy content in grass hay. Consumption of bulky feed leads to both higher GIT development and content. Our findings coincide with those of Diaz et al. (2002) working with pasture- and stall-fed lambs.

EUROP classification system for carcasses based on conformation and fatness reflects the amount of flesh (meat) in relation to bone and the amount of visible fat (subcutaneous) on the outside of the carcass, respectively (Johansen et al., 2006). The higher scores for conformation (U — very good) in T100 goats than in animals in other diet groups can be associated with higher intakes of DM, energy and protein, which should lead to increased muscle mass. These results are related to those of carcass compactness: 97, 146, 186 and 212 g/cm for T0, T33, T66 and T100, respectively. Results from the present study coincide with those of Santos-Silva et al. (2002) and Cañeque et al. (2003) that carcass compactness values can be used as indicator of carcass conformation for the carcasses weighing less than 13 kg. On the other hand, the observed similarity in scores for fatness between T100 and T66 goats indicated lack of linearity between energy intake and fat deposition in goat carcasses. Goats, unlike sheep, deposit less fat in the carcass and more in the visceral (Babiker et al., 1990; Webb et al., 2005). However, considering conformation and fatness scores, carcasses from

both T100 and T66 goats might fetch a premium price in domestic and international markets.

4.3. Carcass physical and chemical compositions

The observed higher levels of fatness in carcasses for concentrate supplemented goats, both when determined physically and chemically, are basically due to higher intake of energy. These findings agree with various reports comparing effects of dietary energy density on carcass composition (Santos-Silva et al., 2002; Diaz et al., 2002). Although it is reported that generally goats deposit less fat in carcasses and more of it around viscera, results from the present study show that energy intake impacted carcass fatness significantly. The observed proportion of dissectible lean in the present study (60–65%) is in agreement with values reported by Webb et al. (2005), but that of fat (3–17%) is higher than the range reported by the same authors (5–14%), probably due to breed difference. The proportion of lean meat, fat and bone in carcasses determines the relative merit of different breeds for meat production (Shadnoush et al., 2004).

4.4. Muscle physico-chemical properties

The rates of muscle pH and temperature decline during the immediate post-mortem period generally have remarkable effects on meat quality attributes (Diaz et al., 2002; Abdullah and Musallam, 2007). In the present study, muscle pH-values for T66 and T100 were below 6 after 6 h PM while values for T0 goats remained above 6 even after completion of glycolysis (24 h PM). The ultimate muscle pH (pHu) for T66 and T100 goats was within the acceptable range (5.6–5.8) reported for goat and sheep carcasses (Braggins, 1996; Pratiwi et al., 2007), although high pHu values for goat muscles are prevalent in literature (Webb et al., 2005). A high pHu generally reflects depletion of muscle glycogen due to stress or other factors (Braggins, 1996; Dhanda et al., 2003). Goats in the present study were, however, not stressed as they were slaughtered in an establishment close to the feeding house. The use of castrates, which are less prone to stress than entire males (Scerra et al., 2001; Destefanis et al., 2003) might be another factor for the observed discrepancy. The observed higher pHu for both T0 and T33 goats can therefore be associated with low glycogen reserves due to nutritional insufficiency although Abdullah and Musallam (2007) found that different energy diets fed to kids did not affect muscle pH and temperature values, probably due to the difference in make-up of feeds and energy levels between the studies. The displayed difference in carcass temperature decline (Fig. 2) between animals in different diet groups may result from the variation in their fat cover. A similar pattern of carcass temperature decline was observed between castrated and intact male goats with different levels of fat cover (Abdullah and Musallam, 2007).

The values for cooking loss in the present study were within the range (26.5–29.2%) reported by Abdullah and Musallam (2007). The observed lower cooking losses for T0 and T33 goats can be linked to their higher pHu than in other diet groups. Variation in meat pH affects cooking losses; with lower losses in high pHu meat (Dhanda et al., 2003; Pratiwi et al., 2007). High pH promotes high water binding (low drip loss and cooking loss) due to higher net charges and greater space between myofilaments (Huff-Lonergan and Lonergan, 2005). As the net charge of myofilaments approaches zero (isoelectric point) with decline in pH, repulsion of myofilaments is reduced allowing them to pack more closely together. Results in the present study concur with Scerra et al. (2001) but differ from Kannan et al. (2006) and Abdullah and Musallam (2007), that dietary energy level did not alter cooking loss percentage in longissimus muscle of kids fed different energy levels. Although cooking loss in muscle may depend on pHu and cooking condition, pH variation must however be of a certain magnitude in order to affect cooking loss. Overall, although higher cooking loss might indicate less juicy meat (Santos-Silva et al., 2002), it is expected that meat from concentrate supplemented goats will be juicier than that from un-supplemented ones because of higher fat content of muscle in the former than in the latter, especially intramuscular fat (Sañudo et al., 2000). The observed variation in cooking loss for individual muscles studied concurs with Pratiwi et al. (2007) who reported that cooking losses were different for muscles taken from different anatomical regions. Further, the displayed similarity in percentage cooking loss between *Triceps brachii* and *Vastus lateralis* muscles is in agreement with the report from the same authors.

In general, meat with Warner–Bratzler shear force values that exceed 55 N would be considered as objectionably tough both by a trained sensory panel and by consumers (Abdullah and Musallam, 2007). Therefore, the pooled shear force values obtained in the present study for the muscles from castrated crossbred goats on different diets groups can be considered acceptably tender, although reports on goat meat tenderness suggest that goat meat does not readily attain a highly acceptable degree of tenderness (Webb et al., 2005). Moreover, although dietary energy intake and consequent carcass fatness affect meat tenderness (Wood et al., 1999), dietary treatments and possibly the goat breed used in the present study did not cause a large enough difference in fatness between treatment groups to be able to observe a significant effect of concentrate supplementation on WBSF. Results from the present study concur with data given by Andrae et al. (2001). An increased amount of subcutaneous and intermuscular fat prevents carcasses from drying out during hanging (Abdullah and Musallam, 2007) and from the impact of rates of carcass cooling (Kannan et al., 2006). Rapid temperature decline in carcasses causes cold shortening in muscles and subsequent meat toughness provided that the energy level is adequate to cause contraction. In the present study, conditions were not suitable for cold-shortening to occur: carcass temperature did not fall below 10 °C before the pH-value of 6 was attained in T66 and T100 goats. On the other hand, the observed variation in shear force value between muscles of different anatomical locations in the carcass is probably a reflection of their differential involvement in physical activity and contents and structure (extent of cross-links) of collagen fibers. For individual muscle applications, *M. gluteobiceps* (73 N), *M. vastus lateralis* (67 N) and *M. semimembranosus* (65 N) can be regarded as objectionably tough whereas the remaining muscles fall in the tender range (with WBSF less than 55 N).

In the present study, shear force values for cooked LD muscle decreased with ageing in a curvilinear fashion, with

the least value after six days of ageing. Thus, the major part of post-mortem tenderisation of chevon occurred 6 days post-mortem, after which increase in tenderness was minimal. These results concur with Kannan et al. (2002). Activities of protease enzymes, especially μ-calpain are responsible for tenderisation of meat during ageing (Christensen et al., 2004; Koohmaraie and Geesink, 2006).

5. Conclusion

This study has generated baseline information on the quality characteristics of carcass and meat from Small East African × Norwegian crossbred goats finished on a wide range of concentrate supplementation. Increasing the proportion of concentrate in the diet resulted in an improvement in growth performance, carcass and meat quality. Carcass dressing values increased with concentrate supplementation which guarantees better prices. Carcass fatness score improved to adequate levels ensuring carcass protection against drying out during hanging and transportation and against cold shortening during cold storage. However, the duration for which goats should be under concentrate finishing diets will depend on economics of such enterprise. Overall, finishing Small East African × Norwegian crossbred goats at 66% access to their *ad libitum* concentrate intake gives optimum carcass and meat quality, and that any increase above this level seems not to improve meat production.

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