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Growth and distribution of non-carcass components of Small East African and F1 Norwegian crossbred goats under concentrate diets

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ABSTRACT

To assess the effects of levels of concentrate diet on growth and distribution of non-carcass components of feedlot-finished goats, 23 castrated Small East African-SEA (14.5 ± 0.5 month old and 20.1 ± 1.2 kg BWT) and 32 castrated F1 Norwegian crossbred (9.5 ± 0.5 month old, 17.1 ± 1.2 kg BWT) goats were allotted to 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* allowance (T66) and 100% access to *ad libitum* allowance (T100). Each animal had access to *ad libitum* grass hay. The weight of head, hocks and empty gastro intestinal tract as percentage of empty body weight (EBW) decreased ($P<0.05$) with increasing levels of concentrate supplementation. The weight of liver as percentage of EBW increased ($P<0.05$) with increasing levels of supplementation. Similarly, percentage of total non-carcass fat in both total body fat (TBF) and EBW increased ($P<0.05$) with increasing levels of supplementation, mainly due to omental fat. Seemingly, percentages of total non-carcass fat in TBF for crossbred goats were numerically greater than that of SEA goats. Relative to EBW, liver had allometric growth coefficient greater than one, for both genotypes. Relative to both EBW and TBF, growth rate of omental fat was the fastest followed by kidney, mesenteric and pelvic fats. It is concluded that liver mass is responsive to dietary nutrient density and goats preferentially deposit fat internally as omental fat. Moreover, crossbred goats have higher proportion of non-carcass fat than SEA goats.

1. Introduction

In Tanzania, goats are raised on traditional system based on range pastures. Under this system, goats make use of the marginal grazing and browsing lands, which cover most of the country. The quality and quantity of the range pastures, however, are declining in recent years (Mtengeti et al., 2006; Rubanza et al., 2007). This decline suggests that goats need to be supplemented with energy in their diet to be able to meet their maintenance and production requirements.

Although value of meat animals is mainly associated with carcass yield, parts of non-carcass components are also edible in most developing countries (Sebsibe et al., 2007). Similarly, in some developed countries, meat industry is interested in certain qualitative and quantitative characteristics of non-carcass components such as liver, heart, kidneys, brain, spleen, lungs and other similar organs (Moron-Fuenmayor and Clavero, 1999). In this case, non-carcass components might compete with carcass components with respect to economic gains from meat animals. Moreover, non-carcass components such as gut fill, hides, feet, head, alimentary tract and viscera may affect dressing percentage as growth proceeds (Vieira et al., 2006). The growth of non-carcass

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components in meat animals is thus an important part of the total growth process. Reports show that the productive efficiency of offals and other non-carcass components is affected by the nutritional status of the animals (Moron-Fuenmayor and Clavero, 1999). This relationship suggests that components of growth for meat animals can be varied through dietary manipulation.

Fat tissue is both a carcass and non-carcass component. Fat in the carcass has beneficial roles with respect to reducing dehydration and cold-shortening during the cooling process (Louvandini et al., 2006). Non-carcass fat, on the other hand, acts as protective pad for internal organs. Overall, both carcass and non-carcass fat depots serve as energy stores, providing a survival buffer against periodic food scarcity such as in drought (Afonso and Thompson, 1996; Negussie et al., 2003). Research findings show that, onset of fattening and distribution of fat in domestic animals is affected by breed and plane of nutrition (Wood et al., 1999; Sanudo et al., 1998; Andersen et al., 2005; Warren et al., 2008). Animals bred for milk production deposit more fat internally around viscera while those bred for meat production deposit more of it in the carcass fat depots (Teixeira et al., 1996; Negussie et al., 2003). Animals fattened on pasture generally have less body fat than those on concentrate (Diaz et al., 2002). Studies with goats, however, have focused on effects of dietary manipulation on carcass yield. There is limited information on the effect of dietary regimen on non-carcass yield. The objective of the present study was therefore to assess the effects of levels of concentrate diet on growth and distribution of non-carcass components of feedlot-finished Small East African goats and their crosses with Norwegian goats.

2. Materials and methods

2.1. Animals and treatments

Two separate experiments were carried out in this study. The first experiment involved 23 castrated Small East African-SEA (14.5 ± 0.5 month old and 20.1 ± 1.2 kg BWT) while the second involved 32 castrated F1 SEA/Norwegian crossbred goats (9.5 ± 0.5 month old and 17.1 ± 1.2 kg BWT). The goats were bought from Mulbadaw Farm in the Northern part of Tanzania and brought to a research unit of the Department of Animal Science, Sokoine University of Agriculture.

In both experiments, goats were divided into blocks of four similar animals, based on live weight. Accordingly, goats were assigned at random, within blocks, to one of four dietary treatments in a completely randomised block design. Dietary treatments were T0, where no concentrate supplementation was offered; T33 and T66 where weight of concentrate on offer (as fed) consisted 33% and 66%, respectively of *ad libitum* concentrate intake. The fourth treatment, T100, involved feeding concentrate *ad libitum* allowing 10% refusal rate. Grass hay, as a basal diet, was offered *ad libitum* to all goats.

2.2. Feeding management

Animals were given a three-week adaptation period during which they were treated with Ivermectin against internal and external parasites. Each goat had *ad libitum* access to water and hay in addition to 150 g (as fed) of concentrate feed per day during this period. During the experimental period of 90 days, goats were individually fed in the first experiment but group-fed, with four goats per pen, in the second experiment. Animals were fed twice daily for both hay and concentrate; water was available *ad libitum*. Amount of both hay and concentrate on offer and refusals were weighed daily to obtain feed intake.

2.3. Slaughter of experimental goats

Animals were weighed in two consecutive days before slaughter to obtain final live weight (FLW) and fasted for about 16 h and weighed again to get the slaughter live weight (SLW). All goats were slaughtered 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 carpus-metacarpal and tarsus-metatarsal joints, respectively. The following non-carcass components were weighed: blood, head, skin, hocks, internal organs (kidneys, liver, spleen, genitals, heart, lung and trachea and diaphragm), internal fat depots (kidney, pelvic, omental, mesenteric, heart and scrotal) and digestive tract (full and empty). Blood, head, skin, hocks and genitals were further classified as sub-products. Weights of kidney, pelvic, omental, mesenteric, heart and scrotal fat depots were added as total non-carcass fat (TNCF). 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 were dissected into two equal halves through the median plane using a band saw, 45 min post-mortem. The weights of half-carcasses were recorded. The carcasses were then chilled at 0 °C for 24 h after which they were weighed again to obtain cold carcass weights. The left-half-carcasses were dissected into muscle, fat and bone for estimation of carcass composition. Weights of fat in the half-carcass (subcutaneous and intermuscular) were doubled to obtain total carcass fat (TCF). Total carcass fat was added to total non-carcass fat to obtain total body fat (TBF).

2.4. Physical and chemical compositions of dietary feeds

The grass hay consisted of *Bracharia* spp. (70%) and *Bothrocloa* spp. (30%). Chemical and fibre compositions of both the grass hay and concentrate were analyzed according to AOAC (2000) and Vansoest et al. (1991), respectively. In vitro dry matter digestibility and organic matter digestibility were done following the method of Tilley and Terry (1963). Physical composition of concentrate, chemical composition of concentrate and grasses, and digestibility data (in vitro) are reported in Table 1. Metabolisable energy contents of feeds were estimated from their chemical composition following the equation of MAFF (1975): $\mathrm{ME\ (MJ/kg\ DM)} = 0.012\mathrm{CP} + 0.031\mathrm{EE} + 0.005\mathrm{CF} + 0.014\mathrm{NFE}$.

2.5. Statistical analysis

Data from the two experiments were analyzed separately due to the difference in feeding management between them (individual for SEA goats vs. group feeding for crosses) and age-at-slaughter (17.5 months for SEA goats vs. 12.5 months

Table 1
Physical composition of concentrate, chemical composition of concentrate and grass hay and digestibility (in vitro) data of such ingredients.

	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	922.0	834.5
Organic matter	921.0	902.0
Crude protein	162.0	32.8
Ether extract	134.0	12.0
Crude fiber	146.0	353.3
Neutral detergent fiber	472.1	831.0
Acid detergent fiber	156.1	474.0
Ash	51.0	98.0
Nitrogen free extract	429.4	338.4
In vitro dry matter digestibility	546.0	396.0
In vitro organic matter digestibility	546.4	417.0
Metabolisable energy (MJ/kg DM)	13.4	9.2

for crossbreds). Data on non-carcass components were analyzed by fitting a model that considered dietary treatments as fixed effects and residual as random effect using the GLM procedures of SAS (2001). Each individual animal served as an experimental unit for all the variables assessed. Due to small variation in age of animals within treatments, all variables were corrected by animal age as a covariate. In all analyses, when means were significant by ANOVA at $P<0.05$, they were separated by Least Significant Difference test.

To assess the differential growth of individual non-carcass components relative to EBW or TBF, the allometric growth equation of Huxley (1932) was used. The allometric equation of the form $Y=aX^b$ was converted to a logarithmic form as follows: $\mathrm{Log}_{10}Y=\mathrm{Log}_{10}a+b\mathrm{Log}_{10}X$, to make the equation linear. In this equation, Y is the weight of the individual non-carcass component; X is the weight of EBW or TBF; a is the value of Y when $X=1$; and b is the growth coefficient describing proportionate growth of individual non-carcass component relative to EBW or TBF. The weights of individual non-carcass components were thus first transformed to logarithms (base 10). The log transformed weights of non-carcass components were regressed on EBW or TBF using the PROC REG procedure of SAS (2001).

3. Results

3.1. Percentage of sub-products and visceral organs in EBW

For SEA goats, weights of the head and hocks as percentage of EBW decreased numerically with increasing levels of concentrate supplementation (Table 2). The main difference ($P<0.05$) was between supplemented and non-supplemented goats. For the crossbred goats, except for the blood, all sub-product components were affected ($P<0.05$) by concentrate supplementation. Percentages of the head, skin, hocks and genitals decreased ($P<0.05$) with increasing levels of concentrate supplementation. Percentage of the head for T100 was four units lower than that of T0 goats. Overall, percentages of sub-products in the EBW for crossbred goats at lower levels of concentrate supplementation were numerically higher than that of SEA goats.

Table 2
Percentages (LSmeans ± SE) of sub-products in empty body weight for SEA and crossbred goats under concentrate supplementations.

Variable	Treatment				
	T0	T33	T66	T100	SE
SEA goats					
Blood	4.5	4.6	4.9	5.0	0.2
Head	9.4^{a}	7.9^{b}	7.4^{b}	7.3^{b}	0.3
Skin	7.7	6.9	7.4	7.4	0.2
Hocks	4.1^{a}	3.4^{b}	3.2^{b}	3.3^{b}	0.1
Genitals	0.5	0.3	0.3	0.3	0.1
Crossbred goats					
Blood	4.8	4.8	5.0	4.6	0.2
Head	10.9^{a}	8.4^{b}	7.2^{c}	6.8^{c}	0.2
Skin	7.6^{a}	7.4^{a}	7.0^{bc}	7.0^{c}	0.1
Hocks	4.5^{a}	3.3^{b}	3.1^{bc}	3.0^{c}	0.1
Genitals	0.4^{a}	0.3^{ab}	0.2^{b}	0.2^{b}	0.0

[a,b,c]Least square means in the same row lacking a common letter differ ($P<0.05$). T0, T33, T66 and T100 refer to Zero, 33%, 66% and 100% access to *ad libitum* concentrate allowance, respectively. SEA is Small East African goats.

Of the viscera measured in SEA goats, only the liver and kidneys were affected by concentrate supplementation (Table 3). Percentage of kidneys in EBW decreased ($P<0.05$) while that of liver increased ($P<0.05$) with increasing levels of concentrate supplementation. For the crossbred goats, except for the spleen and diaphragm, percentages of all other viscera in EBW were affected ($P<0.05$) by the levels of concentrate supplementation (Table 3). Percentages of kidney, empty GIT, heart, lung and trachea decreased ($P<0.05$) with increasing levels of concentrate supplementation. Percentage of liver, on the other hand, increased ($P<0.05$) with increasing levels of concentrate supplementation. Generally, except for spleen and diaphragm, percentages of viscera in EBW for crossbred goats were numerically higher than that of SEA goats.

Table 3
Percentages (LSmeans ± SE) of visceral organs in empty body weight for SEA and crossbred goats under concentrate supplementations.

Variable	Treatment				
	T0	T33	T66	T100	SE
SEA goats					
Kidneys	0.4^{a}	0.3^{b}	0.3^{b}	0.3^{b}	0.0
Liver	1.5^{b}	1.6^{b}	1.6^{b}	1.7^{a}	0.1
Spleen	0.2	0.2	0.2	0.2	0.0
Empty GIT	8.5	7.5	7.4	7.2	0.3
Heart	0.6	0.5	0.5	0.5	0.1
Lung and trachea	1.5	1.2	1.3	1.3	0.1
Diaphragm	0.3	0.4	0.4	0.4	0.0
Crossbred goats					
Kidneys	0.5^{a}	0.4^{ab}	0.4^{b}	0.4^{b}	0.0
Liver	1.8^{c}	1.9^{bc}	2.2^{a}	2.1^{a}	0.1
Spleen	0.2	0.2	0.2	0.3	0.0
Empty GIT	10.6^{a}	9.3^{b}	8.2^{c}	7.4^{c}	0.3
Heart	0.8^{a}	0.6^{b}	0.6^{b}	0.6^{b}	0.1
Lung and trachea	1.9^{a}	1.7^{ab}	1.5^{b}	1.5^{b}	0.1
Diaphragm	0.4	0.4	0.4	0.4	0.0

[a,b,c]Least square means in the same row lacking a common letter differ ($P<0.05$).T0, T33, T66 and T100 refer to Zero, 33%, 66% and 100% access to *ad libitum* concentrate allowance, respectively. SEA is Small East African goats.

3.2. Percentage of individual fat depots in EBW and TBF

The percentage of total non-carcass fat (TNCF) in EBW of SEA goats increased numerically with increasing levels of concentrate supplementation (Table 4). The main difference ($P<0.05$) was between supplemented and non-supplemented goats. Although most (except heart and scrotal) individual internal fat depots increased ($P<0.05$) with increasing levels of concentrate supplementation, the main contributor to the TNCF pool were omental and mesenteric depots. As for the SEA goats, percentage of TNCF in EBW for crossbred goats increased ($P<0.05$) with increasing levels of concentrate supplementation; omental, mesenteric, kidney, pelvic and scrotal fat depots were the main contributors to the variation. Apparently, except for the heart fat depot, percentages of individual fat depots in EBW for crossbred goats were higher than that of SEA goats.

For SEA goats, only the percentage of omental fat depot in TBF was affected ($P<0.05$) by concentrate supplementation (Table 5). Supplemented goats had about 4% higher ($P<0.05$) omental fat than non-supplemented ones. For crossbred goats, percentage of TNCF in TBF was affected ($P<0.05$) by concentrate supplementation. Supplemented goats had 29 to 34% higher ($P<0.05$) TNCF than non-supplemented ones. Moreover, the percentage of TNCF depot was numerically higher than that of carcass fat depot for *ad libitum* fed goats. The main contributors to the variation in TNCF were omental, kidney and pelvic fat depots. Seemingly, percentages of TNCF in TBF for crossbred goats were higher than that of SEA goats, mainly due to omental and kidney fat depots.

3.3. Allometric growth coefficients for sub-products and viscera relative to EBW

For SEA goats, except for the blood, all sub-products had allometric growth coefficient less than one (Table 6). A similar pattern was observed in crossbred goats; blood had allometric growth coefficient equal to one whereas other sub-products had allometric growth coefficient less than one. Liver in both SEA and crossbred goats had allometric growth coefficient greater than one. Spleen in SEA goats had allometric growth coefficient greater than one whereas in crossbred goats had allometric growth coefficient equal to one. Other viscera had allometric growth coefficients less than one in both breeds.

3.4. Allometric growth coefficients for different fat depots relative to EBW and TBF

Relative to EBW, most of the fat depots had allometric growth coefficients greater than one for both SEA and crossbred goats (Table 7). Moreover, for each individual fat depot, such coefficients were numerically higher in SEA goats

Table 4
Percentage (LSmeans ± SE) of individual fat depots in empty body weight (EBW) for SEA and crossbred goats under concentrate supplementations.

Variable	Treatment				
	T0	T33	T66	T100	SE
SEA goats					
Carcass fat	2.8^{b}	6.8^{a}	7.2^{a}	7.6^{a}	0.5
Total non-carcass fat	2.5^{b}	5.4^{a}	6.3^{a}	6.6^{a}	0.6
Kidney fat	0.3^{b}	0.7^{a}	0.8^{a}	0.9^{a}	0.1
Pelvic fat	0.3^{b}	0.6^{a}	0.7^{a}	0.7^{a}	0.1
Omental fat	0.8^{b}	2.1^{a}	2.7^{a}	2.6^{a}	0.4
Mesenteric fat	0.7^{b}	1.5^{a}	1.6^{a}	1.8^{a}	0.2
Heart fat	0.2	0.3	0.3	0.4	0.0
Scrotal fat	0.1	0.2	0.2	0.2	0.1
Crossbred goats					
Carcass fat	3.0^{c}	5.8^{b}	8.8^{a}	8.5^{a}	0.4
Total non-carcass fat	1.8^{c}	5.5^{b}	8.8^{a}	9.5^{a}	0.6
Kidney fat	0.2^{c}	0.7^{bc}	1.7^{a}	1.6^{a}	0.2
Pelvic fat	0.2^{b}	0.7^{a}	1.0^{a}	1.0^{a}	0.1
Omental fat	0.4^{d}	2.2^{c}	3.5^{b}	4.4^{a}	0.3
Mesenteric fat	1.0^{c}	1.4^{bc}	1.9^{a}	2.0^{a}	0.2
Heart fat	0.2	0.2	0.2	0.2	0.0
Scrotal fat	0.1^{c}	0.2^{b}	0.4^{a}	0.4^{ab}	0.0

[a,b,c,d]Least square means in the same row lacking a common letter differ ($P<0.05$).T0, T33, T66 and T100 refer to Zero, 33%, 66% and 100% access to *ad libitum* concentrate allowance, respectively. SEA is Small East African goats.

Table 5
Percentage (LSmeans ± SE) of individual fat depots in total body fat (TBF) for SEA and crossbred goats under concentrate supplementations.

Variable	Treatment				
	T0	T33	T66	T100	SE
SEA goats					
Carcass fat	53.1	54.8	53.6	54.8	3.0
Total non-carcass fat	46.9	45.2	46.3	45.2	3.0
Kidney fat	6.8	5.6	5.6	6.1	1.0
Pelvic fat	5.4	5.1	5.6	5.1	1.0
Omental fat	14.5^{b}	19.0^{a}	19.0^{a}	18.0^{a}	2.0
Mesenteric fat	14.3	12.0	13.0	12.2	3.0
Heart fat	2.0	3.0	4.0	3.0	0.6
Scrotal fat	1.3	1.0	2.1	1.4	0.0
Crossbred goats					
Carcass fat	81.4^{a}	52.3^{b}	50.6^{b}	47.7^{b}	3.4
Total non-carcass fat	18.6^{b}	47.7^{a}	49.4^{a}	52.3^{a}	3.4
Kidney fat	1.6^{c}	6.2^{b}	10.0^{a}	9.0^{ab}	1.0
Pelvic fat	1.6^{a}	5.9^{b}	5.1^{b}	5.0^{b}	0.6
Omental fat	4.5^{c}	19.2^{b}	20.0^{b}	24.4^{a}	1.3
Mesenteric fat	9.4	12.4	10.7	10.8	1.7
Heart fat	1.0	2.0	1.2	1.1	0.4
Scrotal fat	1.0	2.1	2.5	2.1	0.3

[a,b,c]Least square means in the same row lacking a common letter differ ($P<0.05$).T0, T33, T66 and T100 refer to Zero, 33%, 66% and 100% access to *ad libitum* concentrate allowance, respectively. SEA is Small East African goats.

Table 6
Allometric growth coefficients for non-carcass components in relation to the empty body weight (EBW) in SEA and crossbred goats.

Variable	SEA			SEA × Norwegian		
	b	SE (b)	R^2	b	SE (b)	R^2
Sub-products						
Blood	1.08	0.12	78.0	1.00	0.05	92.4
Head	0.39	0.07	59.8	0.49	0.04	81.2
Skin	0.80	0.08	82.1	0.90	0.03	97.7
Hocks	0.41	0.07	58.8	0.55	0.04	87.8
Testes	0.36	0.30	1.5	0.63	0.20	26.9
Internal organs						
Empty GIT	0.54	0.11	52.8	0.54	0.05	82.8
Kidneys	0.69	0.22	31.0	0.59	0.08	63.9
Liver	1.15	0.12	82.4	1.13	0.04	96.1
Spleen	1.64	0.34	49.9	1.00	0.14	63.1
Heart	0.56	0.23	22.2	0.65	0.11	54.7
Lung and trachea	0.54	0.23	20.2	0.54	0.07	68.4
Diaphragm	0.97	0.30	33.5	0.87	0.09	76.0

SEA is Small East African goats, GIT is gastro intestinal tract.

Table 7
Allometric growth coefficients for different fat depots in relation to EBW and TBF in SEA and crossbred goats.

Variable	SEA			SEA × Norwegian		
	b	SE (*b*)	R^2	*b*	SE (*b*)	R^2
Relative to EBW						
Total carcass fat	2.90	0.50	61.6	1.93	0.19	80.4
Total non-carcass fat	3.41	0.38	79.1	2.66	0.24	83.4
Kidney fat	3.30	0.44	72.6	3.35	0.42	72.6
Pelvic fat	2.51	0.42	64.4	2.27	0.47	50.0
Omental fat	3.92	0.63	65.1	3.08	0.34	77.0
Mesenteric fat	3.06	0.55	60.8	2.30	0.21	83.6
Heart fat	1.36	0.45	28.7	0.12	0.45	0.3
Scrotal fat	NE	NE	NE	2.46	0.36	67.4
Relative to TBF						
Total carcass fat	0.99	0.04	96.4	0.86	0.03	97.4
Total non-carcass fat	1.03	0.05	95.8	1.17	0.03	97.9
Kidney fat	0.93	0.11	76.8	1.52	0.10	91.3
Pelvic fat	0.79	0.07	86.2	1.03	0.16	63.2
Omental fat	1.28	0.07	93.1	1.39	0.06	95.7
Mesenteric fat	0.89	0.12	70.8	0.89	0.10	76.8
Heart fat	0.49	0.11	50.4	0.11	0.10	1.0
Scrotal fat	NE	NE	NE	1.05	0.13	74.8

NE is non estimable, EBW is empty body weight, TBF is total body fat, SEA is Small East African goats.

than in crossbred. Overall, TNCF depot for both SEA and crossbred goats had allometric growth coefficient greater than that of carcass depot.

Relative to TBF, TNCF for both SEA and crossbred goats had allometric growth coefficient greater than one, although that of crossbred was numerically higher than that of SEA goats (Table 7). Moreover, omental fat for both SEA and crossbred goats and kidney fat for crossbred goats had allometric growth coefficient greater than one.

4. Discussion

4.1. Percentage of sub-products and visceral organs in the EBW

The observed decline in percentage of head and hocks in EBW for both SEA and crossbred goats with increasing levels of concentrate supplementation emphasizes the early maturing nature of these organs (Kamalzadeh et al., 1998; Lambe et al., 2007). Early maturing nature of head is related to the development of brain and bones whereas that of hocks is related to development of bones. Brain and bones mature earlier than other parts of the body (Kamalzadeh et al., 1998). Increase in body weight in growing animals tends to lower the proportion of these organs in the EBW. Since animals on higher levels of concentrate supplementation grew faster than those on lower levels, they thus contained the least proportions of head and hocks in the EBW. The percentages of different sub-products in the EBW recorded in the present study are comparable to those reported by Mahgoub and Lu (1998) for Oman goats and Pena et al. (2007) for Florida goats. The observed tendency for higher percentages of sub-products in EBW for crossbred than for SEA goats is consistent with the findings of Mahgoub and Lu (1998) who reported that goats of a larger breed had higher proportion of head, skin and feet in the EBW than those of a smaller breed.

The increasing percentage of liver in the EBW with increasing level of concentrate supplementation observed in the present study could be linked to the amount of nutrients handled by the liver in higher levels of supplementation. Higher accumulation of glycogen, which binds water, and fat in the liver of goats on higher levels of concentrate supplementation are possible factors for the observed variation. Energy expenditure for liver increases with level of feed intake due to increased metabolic activity, which affects its weight (Mahouachi and Atti, 2005). These results may also suggest that liver exhibit compensatory growth. In line with results from the present study, Sebsibe et al. (2007) working with local Ethiopian goats recorded heavier weights of liver in goats on concentrate level that promoted higher growth rate than in goats with low growth rate. Mattos et al. (2006) reported that yields of liver, as percentage of empty body weight, was significantly higher in goats with *ad libitum* access to concentrate compared to those with 30% restriction to *ad libitum* level. Similarly, Moron-Fuenmayor and Clavero (1999) found that concentrate supplemented lambs had heavier liver than non-supplemented ones. Results from the present study, however, contrast those of Mahgoub et al. (2005) who observed decreasing percentage of liver in EBW of Omani goats with increasing energy intake. The discrepancy noted between studies could be attributed to the difference in magnitude of energy intake among dietary groups, age and breed of animals used.

The decline in the percentage of empty GIT with increasing levels of concentrate supplementation recorded in the present study reflects less fibrous feed handled by animals on higher levels of concentrate supplementation. For goats on lower levels of concentrate to have comparable performance to those on higher levels, they required to consume more dry matter from roughages. It is likely that the increased roughage intake increased energy expenditure by the GIT and stimulated its pronounced development. Similar results were reported by Diaz et al. (2002) and Caneque et al. (2003) working with pasture- and stall-fed lambs.

4.2. Percentage of individual fat depots in EBW and TBF

The observed increase in non-carcass fat with increasing level of concentrate supplementation is chiefly due to increment in energy intake. The displayed tendency for the crossbred goats to have numerically higher percentage of TNCF in EBW, despite being relatively younger than SEA goats, is contrary to the findings by Mahgoub and Lu (1998) and Moran and Wood (1986). The authors noted higher proportions of body fat and non-carcass fat in EBW for smaller early maturing breed than for larger late-maturing breed. Distribution of different fat depots in the body is thus influenced by adaptability of an animal to particular conditions such as stress due to production, starvation and climatic temperature. Results from the present study should, however, be interpreted with caution as animals differed in feeding system, age and possibly level of maturity. Comparing animals of different mature sizes should be handled carefully; although considering age, body weight, carcass weight, birth weight, and level of fatness as covariates has been suggested as possible solutions (Mahgoub and Lu, 1998). Nonetheless, the findings from the present study indicate the suitability of crossbred goats for meat production as non-carcass fat is easily separable at time of slaughter.

The numerical increase in percentage of TNCF in TBF with increasing levels of concentrate supplementation displayed by goats in the present study corroborates reports by Babiker et al. (1990) and Webb et al. (2005). These reports indicate that goats deposit more fat around viscera and less of it in the carcass. The variation in non-carcass fat with concentrate supplementation observed in the present study, mainly due to omental fat, is in agreement with various reports (Cameron et al., 2001; Mahgoub and Lu, 2004; Pena et al., 2007; Sebsibe et al., 2007). Non-carcass fat matures later than carcass fat and hence the pronounced effect of concentrate supplementation in non-carcass compared to carcass depot during finishing period (Cameron et al., 2001; Negussie et al., 2003; Mahgoub and Lu, 2004). Afonso and Thompson (1996) working with sheep, however, reported the allometric growth coefficient of less than one for internal fat relative to TBF. The discrepancy in findings indicates the species difference in growth and partitioning of body fat.

Percentages of TNCF in TBF for crossbred goats were numerically higher than that of SEA goats. Breed and age difference for animals used could explain the observed variation. Animals bred for milk production, like Norwegian goats, deposit more fat internally around viscera while those bred for meat production deposit more of it in the carcass fat depots (Teixeira et al., 1996; Negussie et al., 2003). This is because milk production and lactational stress result in preferential mobilization of non-carcass fat depot. Crossbreeding SEA goats, a meat breed, with Norwegian goats may have influenced the pattern of fat deposition in the crossbred goats. The higher percentage of TNCF in TBF of crossbred goats, despite being younger than SEA goats, emphasizes the breed effect on partitioning of body fat.

4.3. Allometric growth coefficients for sub-product and viscera relative to EBW

The allometric growth coefficients for blood, liver and spleen recorded to be greater than one in the present study may suggest that these components are late maturing than empty body. These results contrast those of Pena et al. (2007) who reported that the allometric growth coefficients for blood, liver and spleen in suckling Florida kids were less than one. Al-Shorepy et al. (2001) asserted that internal organs such as liver, spleen, heart and kidneys grow slowly compared to empty body. Similarly, Kamalzadeh et al. (1998) noted that, relative to live body weight, liver had allometric growth coefficient of less than one. The different ways of evaluating an organ (proportion of live body weight vs. EBW) may lead to different conclusions on the factors for development of organs.

Overall, the observed discrepancy in findings might suggest that goats in the present study displayed compensatory growth after feed restriction in the traditional production system. Although allometric models were independent of concentrate supplementation level, the growth coefficient of greater than one for liver might thus be indicative of its responsiveness to the nutrient flow rate, as discussed in the previous sections (see Table 3). Pena et al. (2007), reported allometric coefficient for lung and trachea of greater than one; the findings which disagree with the present study. Difference in age, slaughter weight, diet and breed between studies could be the factors behind the discrepancy. The observed allometric growth coefficient of less than one for most of the visceral organ emphasizes on their early maturity. These organs have priority for the available nutrients relative to other parts of the body; therefore, they grow faster at early age and mature relatively earlier than whole body (Kamalzadeh et al., 1998).

4.4. Allometric growth coefficients for different fat depots relative to EBW and TBF

Results from the present study showing that most fat depots had growth coefficient greater than one relative to EBW confirm the phenomenon that fat tissue matures late than other tissues in the empty body (Afonso and Thompson, 1996; Wood et al., 1999; Okeudo and Moss, 2007). Moreover, the higher allometric growth coefficient for non-carcass compared to carcass fat depot displayed in the present study is similar to the pattern observed in sheep (Mahgoub and Lodge, 1994). Mtenga et al. (1994) working with male British Saanen goats reported growth coefficients for different fat depots (gut, channel, kidney, subcutaneous, intermuscular) to be greater than one, relative to EBW. Mahgoub and Lodge (1996) reported growth coefficients for kidney fat to be 1.51; for gut fat, 1.49; for urogenital, 1.40; for subcutaneous, 1.85; relative to EBW. Similarly, Pena et al. (2007) recorded allometric growth coefficients greater than one for omental fat relative to EBW.

Relative to TBF, the recorded allometric growth coefficient of greater than one for TNCF for both SEA and crossbred goats emphasizes the late-maturing nature of non-carcass compared to carcass fat depot. Omental fat was the most late-maturing fat depot. In concurrence with the findings from the present study, Aldai et al. (2007) stated that although the internal fat depots are present in slightly large amount in young animals, they are not early maturing as is often thought. Overall, variation in individual fat depots was more accounted for by the variation in TBF (greater R^2) than in EBW, results which are in agreement with the report by Negussie et al. (2003).

5. Conclusion

Results from the present study suggest that various non-carcass components respond differently to concentrate supplementation. Liver mass is enhanced by higher dietary nutrient density and goats preferentially deposit fat internally as omental fat. Moreover, the higher non-carcass fat for the crossbred than SEA goats indicates the suitability of crossbred goats for meat production as non-carcass fat is easily separable at time of slaughter. Owing to the difference in feeding system and age for SEA and crossbred goats used, breed comparison was limited. However, results from the present study do indicate trends on which to base future comparisons.

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