African Journal of Agricultural Research Vol. 5(9), pp. 834-847, 4 May, 2010
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR09.274
ISSN 1991-637X © 2010 Academic Journals

Full Length Research Paper

Effects of small ruminant species and origin (highland and lowland) and length of rest and feeding period on harvest measurements in Ethiopia

G. Abebe[1], G. Kannan[2] and A. L. Goetsch[3]*

[1]Ethiopia Sheep and Goat Productivity Improvement Program, Addis Ababa, Ethiopia.
[2]Agricultural Experiment Station, Fort Valley State University, Fort Valley, GA 31030, USA.
[3]American Institute for Goat Research, Langston University, Langston, OK 73050, USA.

Accepted 30 September, 2009

Yearling goats (G) and sheep (S) from highland (H) and lowland (L) areas of Ethiopia were used to determine effects of species and origin and lengths of rest and feeding on harvest measures, particularly carcass surface lightness. The H goat used was Arsi-Bale, and the L goat was Somali. The fat-tail indigenous H sheep is thought to be an Arsi-Bale genotype, and the fat-rump indigenous L sheep genotype was the Black Head Ogaden. There were two experiments (each a 2 × 2 × 3 factorial), one with rest for 0, 1, and 2 days before slaughter (R0, R1, and R2, respectively) and the second with feeding 0, 2, and 4 weeks (0 week= 2 days rest; 0F, 2F, and 4F, respectively). There were 10 animals per treatment. In the rest experiment, the instrumental color measure L* (indicating lightness) for the hind leg surface 3 day post-slaughter was lower (P<0.05) for H than for L (34.8, 36.3, 37.4, and 38.9 for G-H, G-L, S-H and S-L, respectively). Surface L* on day 3 was increased (P < 0.05) by 1 and 2 days of rest compared with 0 day for goats regardless of origin, but was not affected for sheep (33.2, 36.3, 37.2, 38.5, 37.8 and 38.2 for G-R0, G-R1, G-R2, S-R0, S-R1, and S-R2, respectively). In the feeding experiment, surface L* on day 3 was lower (P < 0.05) for H than for L (36.5, 39.0, 36.2, and 39.8 for G-H, G-L, S-H, and S-L, respectively). Feeding for 4 weeks increased (P<0.05) surface L* on day 3 regardless of species and origin (37.7, 36.8, and 39.2 for F0, F2 and F4, respectively). In summary, goat and sheep carcasses from highland areas of Ethiopia may darken more quickly compared with lowland areas, and 1 or 2 days of rest before slaughter can increase lightness of the surface of goat carcasses.

Key words: Goats, sheep, carcass, slaughter, shelf-life, meat darkening, management.

INTRODUCTION

Based on customer feedback or anecdotal evidence, personnel of many abattoirs in Ethiopia exporting small ruminant carcasses to markets in the Middle East have stated that shelf-life is shorter for animals from highland than lowland areas. Furthermore, it is claimed that the problem of early darkening of carcasses of highland animals exists for both sheep and goats, without a noticeable difference in magnitude. Research documenting these conditions has not been conducted.

In a previous related experiment, Merera et al. (2009) did not observe improvements in instrumental color determinations of sheep carcasses from both lowland and highland areas by resting 2 or 3 days before slaughter or feeding for 2, 4 or 6 weeks compared with 1 day of rest. However, based on instrumental color values of sheep carcasses, it did not appear that stress during purchase, handling, and transportation were appreciable, or, recovery with 1 day of rest was adequate. In this regard, Merera et al. (2009) suggested that in some instances commercial animal harvest might occur with rest of less than one day, which could prevent recovery from stress such as replenishment of muscle glycogen. Therefore, the objectives of this experiment were to determine the effects and interactions of small ruminant

*Corresponding author. E-mail: goetsch@luresext.edu.

species (goats and sheep) and origin (highland and lowland areas of Ethiopia) and lengths of rest and feeding before slaughter on harvest characteristics, notably carcass instrumental color determinations.

MATERIALS AND METHODS

Location and facilities

Two on-farm experiments were conducted under natural conditions near Modjo town, Ethiopia, located approximately 70 km south-east of Addis Ababa. Experiments were carried out from March to April, 2008. Slaughter and associated measurements were performed at facilities of the Organic Export Abattoir. Rest and feeding of animals took place at a private small ruminant feedlot facility located approximately at 0.5 km from the abattoir, consisting of 12 pens of 11 × 3.5 m. Pens were covered, opened at the front, and had an earthen floor.

Experiments and treatments

There was a total of 20 treatments in the two experiments. One experiment considered the length of rest before slaughter and the second looked at different lengths of feeding periods. The treatment arrangement for both experiments was a 2 × 2 × 3 factorial, with two small ruminant species (goats and sheep), two animal origins within Ethiopia (highland and lowland areas), and the length of three resting (0, 1, and 2 days) or feeding periods (0, 2, and 4 weeks). The 2 days-rest treatments were considered to be 0-week feeding treatments. There were 10 animals of each species × origin grouping per rest and feeding period. Highland goats used were Arsi-Bale and lowland goats were Somali. The Arsi-Bale sheep used was thought to be fat-tail indigenous highland sheep genotype. The fat-rump indigenous lowland sheep genotype was the Black Head Ogaden. Based on dentition, all animals were approximately 1 year of age.

Entire male animals (200) were purchased. Procedures for procurement, transportation, and handling were the ones used by abattoirs in the area. Individuals routinely supplying animals for abattoirs were employed and instructed to follow their normal operating procedures. Lowland animals were from a market in the Borana zone of Negelle district, approximately 500 km from the abattoir. Highland animals were obtained from a market in the West Shewa zone of Ginchi district, approximately 200 km from the abattoir. Animals were purchased and transported as components of normally sized lots. After arrival, animals destined for 2- and 4-week feeding treatments were drenched with albendazole (300 mg/60 kg body weight) and sprayed with diazinon (600 g/l water).

Animals arrived at the abattoir early in the morning. During 1- and 2-days rest periods, moderate quality grass hay and water were available *ad libitum* in pens of the feeding facility until approximately 16:00 h the day preceding harvest. At that time, they were moved to a holding pen in the abattoir, with continued water availability but without feed access. Harvest commenced at approximately 07:00 h the next morning. Animals on 2- and 4-week feeding treatments were handled in the same manner until slaughter.

The 80 animals fed for 2 or 4 weeks were randomly allocated to eight groups of 10 and placed in separate pens, with two groups per species × origin groupings. At the end of feeding periods, five animals were randomly removed for harvest from each pen. The same grass hay used for rest treatments was consumed *ad libitum*. However, in addition, a supplement of 20% ground maize, 60% wheat bran, 19.5% noug cake, and 0.5% salt was offered at 222 g/day per animal at 08:00 and 14:00 h. There were no health problems encountered during the experiments.

Measurements

Animals were weighed immediately before slaughter after feed had been withheld overnight. There was intent to also weigh animals on feeding treatments before feed was withdrawn, but this was not achieved for animals fed for 4 weeks. Average daily gain (ADG) values present are based on an initial unshrunk weight and a final shrunk weight and, thus, underestimate actual ADG. Slaughter occurred by exsanguination. Weights of the carcass and non-carcass components, including digesta, were recorded. Empty body weight was estimated as the sum of the carcass and non-carcass components with digesta excluded. Carcasses were stored at 4°C. Muscle pH was measured with a handheld pH meter (Model IQ150; IQ Scientific Instruments, Inc., Carlsbad, CA, USA) in both *longissimus dorsi* muscles, with duplicate readings, at 15 min and 24 h after slaughter. After pH was measured on the day of harvest, a cross section was cut between the 13^{th} and 14^{th} ribs to expose the surface of both *longissimus dorsi* muscles. Following a 30-min 'bloom' time, instrumental color determinations were made with a Hunter MiniScan unit (Model XE Plus 45/0 LAV; Hunter Associates Laboratory, Inc., Reston, VA, USA). Commission Internationale de l'Eclairage (CIE, 1976) L*, a*, and b* values were determined. Hue angle was calculated as $\tan^{-1}(b/a)$ and chroma was estimated as $(a^2 + b^2)/2$ (Francis and Clydesdale, 1975; Hunter and Harold, 1987). At 1, 2, and 3 days post-harvest, the same color determinations were made in duplicate on the surface of both hind legs. When present, surface fat in the area of measurement was trimmed.

Statistical analyses

Data were analyzed by GLM procedures of SAS (1990). Models consisted of species, origin, length of rest or feeding, all two-way interactions, and the three-way interaction. For the feeding experiment, initial body weight (BW) was used as a covariate for ADG. Main effect means for length of rest and feeding are presented when relevant interactions were non-significant ($P > 0.05$). Interaction means are presented when the interaction was significant ($P < 0.05$), except for species × origin. These means are listed for variables for which main effects of species and (or) origin were significant and no relevant interaction was significant, or if no main effect or interaction was significant. Means were separated by least significant difference with a protected F-test. In addition, simple correlation coefficients were determined between pH and color measures.

RESULTS

Rest experiment

BW and mass of the carcass, non-carcass tissues, and digesta

Harvest BW was similar for highland animals among days of rest and for lowland animals, it was greater ($P<0.05$) at 2 days compared with 1 day of rest (Table 1). There was a three-way interaction in empty BW (EBW), reflecting inconsistent differences between species and animal origin and among lengths of rest. Carcass mass in kg

Table 1. Effects of days of rest, species (goats and sheep), and origin (Highland and Lowland areas) on body weight, carcass weight and mass of non-carcass tissues.

		Rest (days)				Highland			Lowland				Goats		Sheep			
Item[1]	**Species**	**0**	**1**	**2**	**SE**	**0 day[2]**	**1 day[2]**	**2 days[2]**	**0 day**	**1 day**	**2 days**	**SE**	**H[3]**	**L[3]**	**H**	**L**	**SE**	**Effect[4]**
Harvest BW (kg)						20.3^{ab}	21.6^{bc}	20.9^{abc}	21.1^{abc}	19.3^{a}	22.0^{c}	0.47						
Empty BW (kg)	Goats					15.7^{bc}	15.9^{c}	15.5^{abc}	14.4^{ab}	15.7^{bc}	15.8^{bc}	0.55						
	Sheep					14.0^{a}	15.7^{bc}	14.9^{abc}	15.1^{abc}	14.0^{a}	15.0^{abc}							
Carcass weight																		
Kg						7.86^{ab}	8.37^{bc}	7.97^{ab}	8.07^{abc}	7.64^{a}	8.45^{c}	0.204	8.35	8.16	7.77	7.94	0.167	SP
% live weight													40.2^{c}	38.7^{b}	37.0^{a}	38.2^{b}	0.56	
% empty BW													53.2	54.0	52.3	54.0	0.60	OR
Non-carcass tissues																		
Total (kg)													7.32	7.12	7.08	6.74	0.229	
Head (kg)													1.44	1.72	1.37	1.48	0.210	
Blood (g)		810^{b}	765^{ab}	730^{b}	18.2								817	720	853	683	21.1	OR
Skin (kg)	Goats					1.65^{cde}	1.61^{cd}	1.60^{c}	1.24^{a}	1.38^{ab}	1.57^{bc}	0.073						
	Sheep					1.62^{cd}	1.81^{def}	1.83^{ef}	1.88^{f}	1.88^{f}	1.90^{f}							
Feet (g)	Goats	630^{b}	585^{b}	615^{b}	17.3													
	Sheep	468^{a}	515^{a}	505^{a}														
													630	590	513	479	14.2	OR
GIT, full (kg)													1.66^{c}	1.66^{c}	1.55^{b}	1.30^{a}	0.032	
GIT, empty (kg)						5.39^{a}	5.70^{ab}	5.58^{ab}	6.43^{c}	6.06^{bc}	7.07^{d}	0.178	5.20^{a}	6.80^{c}	5.90^{b}	6.23^{b}	0.146	
RESP (g)													298	284	317	277	8.1	OR
Liver (g)		324^{a}	356^{b}	349^{b}	7.4								401	358	322	290	8.5	SP, OR
Heart (g)													116	99	100	83	35.4	SP, OR
Spleen (g)													40	40	50	39	2.4	
Kidneys (g)													109	106	84	77	4.6	OR
Testes (g)													179	142	207	188	7.3	SP, OR
% empty BW																		
Head													9.2	10.4	9.2	10.1	0.74	
Skin													10.3^{b}	9.2^{a}	11.8^{c}	12.8^{d}	0.21	
Blood		5.48^{b}	5.02^{a}	4.78^{a}	0.108								5.22^{b}	4.76^{a}	5.75^{c}	4.66^{a}	0.125	

Table 1. Contd.

Feet	Goats	4.23^{d}	3.76^{bc}	3.93^{cd}	0.111												
	Sheep	3.23^{a}	3.47^{ab}	3.40^{a}													
GIT, empty	Goats					10.1^{bc}	10.9^{cde}	10.9^{cde}	11.4^{e}	10.5^{cd}	11.0^{de}	0.32					
	Sheep					10.2^{bcd}	10.1^{bcd}	11.0^{cde}	8.6^{a}	9.4^{ab}	8.7^{a}						
RESP													1.91	1.87	2.13	1.90	0.047	SP, OR
Liver						2.20^{ab}	2.43^{cd}	2.48^{d}	2.18^{ab}	2.27^{bc}	2.07^{a}	0.064	2.57	2.36	2.17	1.99	0.052	SP
Heart													0.74	0.66	0.67	0.57	0.021	SP
Spleen													0.26^{a}	0.27^{a}	0.34^{b}	0.27^{a}	0.016	
Kidneys	Goats	0.80^{d}	0.64^{bc}	0.66^{c}	0.034													
	Sheep	0.54^{a}	0.55^{ab}	0.55^{a}														
Testes													1.15	0.94	1.40	1.28	0.048	SP, OR
Digesta																		
Kg						3.88^{a}	4.04^{a}	3.92^{a}	4.96^{b}	4.60^{b}	5.55^{c}	0.158	3.54^{a}	5.14^{c}	4.35^{b}	4.93^{c}	0.129	
% live weight													17.0^{a}	24.3^{c}	20.7^{b}	23.7^{c}	0.44	
% empty BW		30.1^{ab}	28.5^{a}	31.0^{b}	0.68								22.6^{a}	34.0^{c}	29.4^{b}	33.6^{c}	0.78	

[1]BW = body weight; GIT = gastrointestinal tract; RESP = respiratory tract. [2]Days of rest before harvest. [3]H = Highland; L = Lowland.[4]SP = species, OR = origin ($P < 0.05$). Abbreviations are shown when interactions involving these main effects were non-significant ($P > 0.05$). [a,b,c,d,e,f] Means within rest, species x rest, origin x rest, or species x origin groupings without a common superscript letter differ ($P < 0.05$).

was greater for goats than for sheep ($P < 0.05$). There was an interaction between origin and length of rest ($P < 0.05$) in carcass mass in kg whereas values for highland animals increased and then decreased; and, those for lowland animals decreased and then increased as the length of rest increased ($P < 0.05$). There was an interaction ($P < 0.05$) between species and origin in carcass mass as a % of BW (that is, dressing percentage); values ranked ($P < 0.05$) highland goats > lowland goats and sheep > highland sheep. For carcass mass as a % of EBW, values were greater for lowland vs. highland animals ($P < 0.05$).

Mass of non-carcass tissues is presented in Table 1 in kg or g and % EBW. Because of the three-way interaction in EBW, non-carcass tissue mass values expressed relative to EBW are addressed thus.

Skin mass was less for goats than that for sheep ($P < 0.05$), with a greater difference between lowland than highland animals ($P< 0.05$; Table 1). Skin mass of goats was greater for the highland than for the lowland origin, but skin mass of sheep was less for the highland origin ($P < 0.05$). Feet mass was greater for goats than for sheep with 0 and 2 days of rest ($P < 0.05$) and also tended to be greater ($P < 0.08$) with 1 day. There was a three-way interaction in mass of the empty gastrointestinal tract ($P < 0.05$). Mass of the digestive tract was greater for lowland goats compared with sheep ($P < 0.05$; 23.3%) but it was similar between species from the highland origin. Liver mass was considerably greater (18.5%) for goats than for sheep ($P < 0.05$). There was an interaction in liver mass between animal origin and day of rest ($P < 0.05$). Mass of testes was greater in sheep than in goats and for highland than for lowland animals ($P<0.05$). Digesta mass in kg, % BW, and % EBW ranked ($P < 0.05$) highland goats < highland and lowland sheep < lowland goats.

pH and color measures

Carcass pH at 15 min after slaughter was affected by two-way interactions between length of rest and species and animal origin ($P < 0.05$), but differences in values were fairly small (Table 2). At 24 h post-slaughter, carcass pH ranked

Table 2. Effects of days of rest, species (goats vs. sheep), and origin (highland vs. lowland areas) on carcass pH and instrumental color measures.

		Rest (d)				Highland			Lowland				Goats		Sheep			
Item	**Species**	**0**	**1**	**2**	**SE**	**0 day[1]**	**1 day[1]**	**2 days[1]**	**0 day**	**1 day**	**2 days**	**SE**	**H[2]**	**L[2]**	**H**	**L**	**SE**	**Effect[3]**
pH																		
15 min	Goats	6.64^{a}	6.74^{b}	6.66^{ab}	0.036													
	Sheep	6.75^{b}	6.63^{a}	6.65^{ab}														
						6.67^{b}	6.65^{b}	6.54^{a}	6.72^{bc}	6.72^{bc}	6.77^{c}	0.036						
24 h						5.91^{a}	5.86^{a}	5.83^{a}	6.34^{c}	6.16^{b}	5.91^{a}	0.047	5.91^{ab}	6.29^{c}	5.82^{a}	5.98^{b}	0.039	
***Longissimus dorsi* cross section (day 0)**																		
L*													36.0	39.7	35.0	37.9	0.51	SP, OR
a*						9.2^{b}	7.4^{a}	8.5^{b}	9.3^{b}	9.0^{b}	8.9^{b}	0.29	8.7^{b}	7.9^{a}	8.0^{a}	10.2^{c}	0.24	
b*						10.0^{b}	8.3^{a}	10.3^{b}	10.5^{bc}	10.7^{bc}	11.1^{c}	0.31	10.1^{b}	10.4^{bc}	9.0^{a}	11.1^{c}	0.25	
Hue angle		47.9^{a}	49.3^{a}	51.1^{b}	0.53								49.2^{a}	52.6^{b}	48.3^{b}	47.6^{b}	0.62	
Chroma						13.6^{b}	11.1^{a}	13.3^{b}	14.0^{b}	14.1^{b}	14.3^{b}	0.39	13.4^{b}	13.1^{b}	12.0^{a}	15.1^{c}	0.32	
Hind leg surface, L*																		
Day 1	Goats					37.7^{de}	36.5^{bcd}	34.2^{b}	34.2^{b}	39.0^{e}	34.5^{b}	0.81						
	Sheep					36.8^{cde}	36.3^{bcd}	35.0^{bc}	36.2^{bcd}	34.3^{b}	31.2^{a}							
Day 2						36.9^{c}	35.4^{ab}	34.9^{a}	35.8^{abc}	36.8^{c}	36.8^{c}	0.51	34.5^{a}	36.1^{b}	37.0^{b}	36.8^{b}	0.42	
Day 3	Goats	33.2^{a}	36.3^{b}	37.2^{bc}	0.56													
	Sheep	38.5^{c}	37.8^{bc}	38.2^{c}														
													34.8	36.3	37.4	38.9	0.45	OR
a*																		
Day 1	Goats					6.8^{bc}	6.1^{ab}	7.7^{de}	8.3^{e}	7.4^{cde}	9.7^{fg}	0.41						
	Sheep					7.1^{bcd}	5.0^{a}	6.4^{bc}	8.6^{ef}	9.9^{fg}	10.3^{g}							
Day 2		7.9^{a}	9.2^{b}	9.0^{b}	0.20	6.4^{a}	9.3^{b}	8.7^{b}	9.4^{b}	9.0^{b}	9.4^{b}	0.28						
Day 3						8.8^{ab}	10.3^{b}	8.6^{ab}	8.3^{a}	8.0^{a}	9.2^{b}	0.29	8.9	8.2	9.5	8.8	0.24	SP
b*																		
Day 1													4.4	9.7	4.5	8.9	0.30	OR
Day 2		7.7^{a}	10.6^{c}	8.8^{b}	0.29								8.3^{a}	9.4^{b}	9.2^{ab}	9.2^{ab}	0.34	
Day 3	Goats	7.3^{a}	10.7^{c}	9.0^{b}	0.40													
	Sheep	10.2^{c}	10.4^{c}	8.9^{b}														
						9.8^{c}	12.9^{d}	8.7^{ab}	7.7^{a}	8.2^{ab}	9.2^{bc}	0.40	9.7^{b}	8.3^{a}	11.3^{c}	8.4^{a}	0.33	

Table 2. Contd.

Hue angle																
Day 1		39.9^{ab}	42.5^{b}	36.9^{a}	1.20								31.7^{a}	49.2^{c}	35.3^{a}	43.0^{b}	1.32
Day 2	Goats	40.9^{a}	50.1^{d}	42.9^{ab}	1.10												
	Sheep	45.3^{bc}	47.5^{cd}	45.1^{bc}													
						40.5^{a}	50.2^{c}	46.3^{b}	45.7^{b}	47.4^{bc}	41.7^{a}	1.10	43.4^{a}	45.9^{bc}	48.0^{c}	43.9^{ab}	0.90
Day 3	Goats	42.2^{a}	49.5^{c}	45.8^{abc}	1.15												
	Sheep	47.8^{bc}	46.7^{bc}	44.5^{ab}													
						47.3^{b}	51.5^{c}	45.2^{ab}	42.7^{a}	44.7^{ab}	45.0^{ab}	1.15	46.6^{b}	45.0^{ab}	49.4^{c}	43.3^{a}	0.95
Chroma																	
Day 1						8.5^{b}	7.0^{a}	8.4^{b}	12.5^{c}	13.1^{c}	13.5^{c}	0.40					
Day 2						8.7^{a}	14.8^{c}	12.6^{b}	13.4^{b}	13.4^{b}	12.6^{b}	0.44					
Day 3	Goats	10.9^{a}	14.1^{c}	12.6^{b}	0.43												
	Sheep	13.7^{bc}	14.1^{c}	12.8^{b}													
						13.3^{b}	16.6^{c}	12.3^{ab}	11.4^{a}	11.6^{a}	13.0^{b}	0.43					

[1]Days of rest before harvest. [2]H = Highland; L = Lowland. [3]SP = species, OR = origin (P < 0.05). Abbreviations are shown when interactions involving these main effects were nonsignificant (P > 0.05).
[a,b,c,d,e,f,g]Means within rest, species x rest, origin x rest, or species x origin groupings without a common superscript letter differ (P < 0.05).

(P<0.05) lowland goats > lowland sheep > highland sheep, with the value for highland goats intermediate (P>0.05) to those for highland and lowland sheep. The L* value, as a measure of lightness, of the *longissimus dorsi* muscle cross section on day 0 was greater for goats than for sheep and greater for lowland than for highland animals (P < 0.05; Table 2). The a* value, indicative of redness, ranked (P < 0.05) lowland goats and highland sheep < highland goats < lowland sheep. Also, a* was lowest among origin × rest length treatments for highland animals with 1 day of rest (P < 0.05). The b* value, reflecting yellowness, was similar between origins for goats but considerably greater for lowland compared with highland sheep (P < 0.05). The b* value for highland animals was less with 1 than 0 and 2 days of rest (P < 0.05) and was similar among lengths of rest for lowland animals. The hue angle, for an indication of discoloration, was greater for 2 than for 0 and 1 day of rest (P < 0.05), and was greatest among species × origin treatments for lowland goats (P<0.05). Chroma or the saturation index, as a measure of color intensity, ranked highland sheep < highland and lowland goats < lowland sheep (P < 0.05). As expected, based on differences in a* and b* values, Chroma was lowest among origin × rest length treatments for highland animals rested for 1 day (P < 0.05).

The significance of interactions in instrumental color determinations for the hind leg surface was not consistent among days post-slaughter (Table 2). Because measurements at 2 days post-slaughter and, in particular 3 days, are more pertinent to the issue of short-shelf life or early darkening compared with measures at 1 day, they are addressed as follows.

On day 2 after slaughter, the L* value for the hind leg surface was greater for lowland than for highland goats (P < 0.05) but was similar between origins of sheep (Table 2). The L* value on day 2 was not improved (that is, increased) with either animal origin by increasing length of rest. The a* value on day 2 was lower for highland animals with 0 day of rest compared with other origin × rest length treatments (P<0.05). The b* value on day 2 ranked (P < 0.05) 0 < 2 < 3 days of rest. The b* value was greater for lowland vs. highland goats (P < 0.05), with intermediate (P > 0.05) values for sheep. Hue angle on day 2 was greater for goats rested 1 than 0 and 2 days (P<0.05) but was similar among lengths of rest for sheep. Chroma on day 2 for highland animals ranked (P< 0.05)

0 < 2 < 1 days of rest but was similar among days of rest for lowland animals, with means similar to that for highland animals rested for 2 days.

On day 3 post-slaughter, the L* value for the hind leg surface was greater for Lowland than for highland goats and sheep (P < 0.05; Table 2). Furthermore,1 and 2 days of rest increased L* compared with 0 day for goats (P<0.05) but not for sheep. At day 3, goat carcasses had a higher a* than carcasses of sheep (P<0.05). There was an interaction in a* between origin and length of rest (P < 0.05); for lowland animals rested for 2 days, a* increased compared with 0 and 1 day (P < 0.05), although with highland animals, values were similar among rest lengths. The b* value for goats on day 3 increased and then decreased with increasing length of rest (P < 0.05), whereas for sheep the value for 2 days of rest was greater than for 0 and 1 day (P < 0.05). Hue angle was similar among lengths of rest for sheep but was lower for goats with 0 than 1 day of rest (P <0.05). Chroma for goats ranked (P < 0.05) 0 < 2 < 1 days of rest and for sheep was less for 2 days of rest than for 0 and 1 days (P<0.05).

Feeding experiment

BW and ADG and mass of the carcass, non-carcass tissues, and digesta

Harvest or slaughter BW was greater for feeding of goats and sheep at 2 weeks than at 0 week (13.8 and 13.7%, respectively) (P < 0.05; Table 3). However, slaughter BW of goats fed for 4 weeks was less than for those that were not fed (0 week) and for those fed for 2 weeks (P<0.05); slaughter BW of sheep fed for 4 weeks was similar to that of sheep fed for 2 weeks. In accordance, ADG was greater for the 2- than for the 4- week feeding period length. There was a three-way interaction in EBW (P < 0.05). For goats of both origins, feeding for 2 weeks increased EBW, although for goats from the lowland origin fed for 4 weeks, EBW was similar to that for 0 week. The EBW of highland goats fed for 4 weeks was lowest among feeding period lengths (P<0.05). Feeding sheep resulted in increased (P < 0.05) EBW regardless of length of the period; although the difference between lowland sheep fed for 4 weeks was not different from 0 week (P>0.05).

Carcass weight of goats was greater for feeding 2 than 0 and 4 weeks and that for sheep was greater for feeding in 2 than 0 weeks (P<0.05; Table 3). Carcass weight in % BW (that is, dressing %) was similar between species in most instances. There were no consistent changes in dressing % with advancing length of the feeding period for species × origin treatments. Carcass weight in % EBW was greater for feeding in 2 than 0 and 4 weeks goats compared with sheep, and the lowland than highland origin (P<0.05).

Feeding for 2 and 4 weeks decreased skin mass in % EBW (P < 0.05; Table 3). Skin mass was less for goats than for sheep (P < 0.05), similar between goat origins, and greater for lowland compared with highland sheep (P < 0.05). Mass of the empty digestive tract was greater in feeding for 4 weeks than for 0 and 2 weeks for highland animals and for lowland animals ranked (P < 0.05) 0 < 2 < 4 weeks. Mass of the digestive tract was similar between species from the highland origin but was greater for lowland goats than for sheep (P < 0.05). For all but two species comparisons within origin × feeding period groupings, liver mass was greater for goats than for sheep (P < 0.05). Liver mass was in most cases greater for highland than for lowland animals, and in some instances was greater for 2- and (or) 4- week feeding periods compared with 0 week.

pH and color measures

At 15 min post-slaughter, carcass pH for highland animals was greater for 4- than for 0- and 2- week feeding periods and for lowland animals, it was greater for 0 than for 2 weeks, although magnitudes of difference were not marked (Table 4). At 24 h post-slaughter, carcass pH was greater for goats compared with sheep with 0 and 4 weeks-feeding (P < 0.05) but was similar between species with 2 weeks of feeding. Carcass pH at 24 h was similar between origins for goats, greater for highland than for lowland sheep (P < 0.05), similar between highland sheep and goats, and greater for lowland goats vs. sheep (P < 0.05).

There was a three-way interaction in L* of the cross section of the *longissimus dorsi* muscle on day 0 (Table 4). This was primarily attributable to a relatively high value for 0 week of feeding for lowland goats and further increases when fed for 2 and 4 weeks (P < 0.05). A three-way interaction in a* was due largely to relatively high values for highland goats and lowland sheep fed for 2 weeks and the lowest value among species × origin × feeding period length treatments for lowland goats fed for 4 weeks (P<0.05). The b* value was greater for 2 compared with 4 weeks of feeding and for lowland than for highland goats (P < 0.05). Chroma was similar among species for feeding period lengths of 0 and 2 weeks but was greater for sheep than for goats with 4 weeks of feeding (P < 0.05). With both species, Chroma increased and decreased with increasing length of the feeding period (P < 0.05), with a greater magnitude of decline for goats than for sheep.

The L* value on day 2 post-slaughter for the hind leg surface was greater for goats fed 2 and 4 weeks compared with 0 week (P < 0.05), whereas for sheep the value for 4 weeks was greatest among feeding period lengths (P < 0.05; Table 4). The L* value for highland animals was similar among feeding period lengths but for lowland animals was greater for 4 than for 0 and 2 weeks of feeding (P < 0.05). On day 3 post-slaughter, the L* value was greater for lowland compared with highland

Table 3. Effects of length of feeding, species (goats vs sheep), and origin (highland vs. lowland areas) on body weight, carcass weight, and mass of non-carcass tissues.

		Feeding length (week)				Highland			Lowland				Goats		Sheep			
Item[1]	**Species**	**0**	**2**	**4**	**SE**	**0 wk[2]**	**2 wk[2]**	**4 wk[2]**	**0 wk**	**2 wk**	**4 wk**	**SE**	**H[3]**	**L[3]**	**H**	**L**	**SE**	**Effect[4]**
BW (kg)																		
Initial (unshrunk)[5]	Goats	21.7^{b}	23.7^{c}	20.0^{a}	0.42								21.1^{a}	22.5^{b}	22.3^{b}	22.1^{b}	0.34	
	Sheep	21.2^{ab}	23.5^{c}	22.0^{b}														
Harvest (shrunk)[6]	Goats	21.7^{bc}	24.7^{e}	20.4^{a}	0.45													
	Sheep	21.2^{ab}	24.1^{de}	22.9^{cd}														
													21.3^{a}	23.2^{b}	22.7^{b}	22.8b	0.37	
Empty BW (kg)	Goats					15.5^{bc}	17.9^{f}	13.5^{a}	15.8^{bcd}	17.1^{ef}	15.8^{bcd}	0.46						
	Sheep					14.9^{b}	17.5^{f}	16.8^{def}	15.0^{b}	16.8^{cdef}	16.0^{bcde}							
ADG (g)			65^{b}	18^{a}	14.9													
Carcass weight																		
Kg	Goats	8.49^{ab}	9.87^{d}	7.97^{a}	0.226													
	Sheep	7.93^{a}	9.20^{c}	8.63^{bc}														
% live weight	Goats					40.0^{bc}	41.2^{c}	38.0^{ab}	38.0^{ab}	38.7^{abc}	39.7^{bc}	0.87						
	Sheep					36.5^{a}	36.2^{abc}	38.6^{abc}	38.7^{abc}	38.0^{a}	36.7^{a}							
% empty BW		53.5^{a}	55.0^{b}	53.4^{a}	0.34								54.3	55.5	52.2	54.0	0.39	SP,OR
Non-carcass tissues																		
Total (kg)	Goats	7.15^{b}	7.64^{c}	6.67^{a}	0.133													
	Sheep	7.02^{ab}	7.89^{c}	7.78^{c}														
						7.22^{ab}	8.01^{c}	7.15^{a}	6.94^{a}	7.53^{b}	7.30^{ab}	0.133	7.10^{a}	7.21^{a}	7.82^{b}	7.30^{ab}	0.109	
Head (kg)						1.38^{a}	1.62^{c}	1.37^{a}	1.47^{b}	1.47^{b}	1.41^{ab}	0.032						
Blood (g)	Goats	745^{ab}	909^{d}	735^{ab}	24.3													
	Sheep	715^{a}	855^{cd}	800^{bc}														
													846	747	873	707	19.8	OR
Skin (kg)	Goats	1.59^{b}	1.53^{b}	1.30^{a}	0.052													
	Sheep	1.87^{c}	1.88^{c}	1.83^{c}														
Feet (g)	Goats	615^{b}	605^{b}	520^{a}	15.8													
	Sheep	505^{a}	530^{a}	495^{a}														
						565^{bc}	595^{c}	480^{a}	555^{bc}	540^{b}	535^{b}	15.8						
GIT, full (kg)						5.58^{a}	7.10^{b}	5.63^{a}	7.07^{b}	7.74^{c}	6.88^{b}	0.169	5.80^{a}	7.64^{d}	6.40^{b}	6.81^{c}	0.138	

Table 3. Contd.

GIT, empty (kg)	Goats	1.71^{b}	1.99^{d}	1.89^{c}	0.046												
	Sheep	1.47^{a}	1.84^{c}	1.85^{c}													
						1.66^{b}	1.96^{d}	1.78^{bc}	1.52^{a}	1.87^{cd}	1.91^{cd}	0.046	1.75^{b}	1.93^{c}	1.84^{bc}	1.59^{a}	0.037	
RESP (g)	Goats	295^{ab}	296^{ab}	276^{a}	9.8												
	Sheep	304^{bc}	324^{cd}	342^{d}													
													303	275	353	294	8.0	OR
Liver (g)	Goats					412^{cd}	487^{f}	366^{bc}	368^{bc}	458^{def}	425de	17.2						
	Sheep					343^{b}	411^{cd}	468^{ef}	273^{a}	373^{bc}	338^{ab}							
Heart (g)	Goats	106^{b}	124^{c}	100^{b}	3.8												
	Sheep	89^{a}	108^{a}	102^{b}													
													105^{b}	115^{c}	110^{bc}	89^{a}	3.1	
Spleen (g)	Goats					41^{ab}	69de	43^{abc}	43^{abc}	60^{cd}	58^{bcd}	6.4						
	Sheep					45^{abc}	66de	82^{e}	38^{a}	69de	54^{abcd}							
Kidneys (g)	Goats	103^{b}	108^{b}	101^{b}	4.3													
	Sheep	82^{a}	100^{b}	109^{b}														
													95^{a}	113^{b}	105^{b}	88^{a}	3.5	
Testes (g)	Goats	162^{ab}	180^{b}	101^{b}	4.3													
	Sheep	212^{c}	210^{c}	228^{c}														
													174	151	225	208	7.0	OR
% empty BW																		
Head						9.08^{ab}	9.16^{bc}	8.99^{ab}	9.56^{c}	8.72^{a}	8.85^{ab}	0.147	8.92^{b}	8.38^{a}	9.23^{b}	9.71^{c}	0.120	
Blood	Goats					5.04^{cde}	5.58^{fg}	5.77^{g}	4.48^{ab}	4.88^{bcd}	4.38^{a}	0.182						
	Sheep					5.37^{defg}	5.43^{efg}	5.18^{def}	4.23^{a}	4.58^{abc}	4.56^{abc}							
Skin		11.3^{b}	9.9^{a}	10.0^{a}	0.19								9.4^{a}	9.1^{a}	11.1^{b}	12.8^{c}	0.21	
Feet		3.66^{b}	3.29^{a}	3.29^{a}	0.608								3.68	3.62	3.18	3.17	0.070	SP
GIT, empty						10.9^{b}	11.1^{b}	11.8^{c}	9.8^{a}	11.1^{b}	12.0^{c}	0.23	11.3^{b}	11.9^{c}	11.2^{b}	10.0^{a}	0.19	
RESP						2.05^{c}	1.92^{bc}	2.22^{d}	1.87^{b}	1.68^{a}	1.77^{ab}	0.056	1.97	1.69	2.15	1.86	0.046	SP
Liver	Goats					2.67^{de}	2.71^{e}	2.71^{e}	2.32^{bcd}	2.69^{e}	2.70^{e}	0.083						
	Sheep					2.29^{bcd}	2.35^{cd}	2.79e	1.83^{a}	2.25^{bc}	2.10^{ab}							
Heart													0.67^{b}	0.71^{b}	0.67^{b}	0.56^{a}	0.018	
Spleen	Goats					0.26^{a}	0.39^{cd}	0.32^{abcd}	0.27^{ab}	0.35^{abcd}	0.36^{abcd}	0.036						
	Sheep					0.30^{abc}	0.37^{bcd}	0.49^{e}	0.26^{a}	0.41^{de}	0.33^{abcd}							
Kidneys													0.61^{b}	0.69^{c}	0.64^{bc}	0.56^{a}	0.019	
Testes													1.12	0.93	1.38	1.31	0.042	SP,OR

Table 3. Contd.

Digesta								
Kg	Goats	3.51^{a}	4.91^{cd}	3.71^{a}	5.98^{ef}	6.35^{f}	4.78^{cd}	0.220
	Sheep	4.33^{bc}	5.36^{d}	3.99^{ab}	5.12^{d}	5.39^{de}	5.16^{d}	
% live weight	Goats	17.0^{a}	20.4^{cd}	19.6^{bc}	26.2^{f}	25.4^{f}	21.9^{cde}	0.85
	Sheep	20.4^{cd}	22.0^{de}	17.5^{ab}	24.1^{ef}	22.6^{de}	22.2^{de}	
% empty BW	Goats	22.8^{a}	27.6^{bc}	27.7^{bcd}	38.1^{g}	37.3^{g}	30.5^{def}	1.48
	Sheep	29.1^{cde}	30.8^{def}	23.8^{ab}	34.2^{fg}	32.5^{ef}	32.4^{def}	

[1]B = body weight; ADG = average daily gain; GIT = gastrointestinal tract; RESP = respiratory tract. [2]Length of the feeding period. The 0-wk length was 2 d of rest before harvest. [3]H = Highland; L = Lowland. [4]SP = species, OR = origin (P < 0.05). Abbreviations are shown when interactions involving these main effects were nonsignificant (P > 0.05).[5]Harvest or slaughter BW was after an overnight period without feed. [6]ADG values are underestimates because final BW was after an overnight period without feed. [a,b,c,d,e,f,g] Means within rest, species x rest, origin x rest, or species x origin groupings without a common superscript letter differ (P < 0.05).

animals (P < 0.05) and was greater for feeding in 4 vs. 0 and 2 weeks (P < 0.05).

The a* value on day 2 post-slaughter for the hind leg surface was lower for feeding in 4 than 0 and 2 weeks with both origins (P < 0.05), and the magnitude of difference was greater for lowland than for highland animals (P < 0.05; Table 4). The a* value on day 2 was similar between highland and lowland goats but was greater for lowland compared with highland sheep (P < 0.05). The a* value on day 2 was greater for lowland than for highland sheep (P < 0.05), although only a tendency for an origin difference existed for goats. Conversely, on day 3, a* was greater for sheep than for goats of both origins (P<0.05).

The b* value for the hind leg surface on day 2 post-slaughter was affected by an interaction between origin and length of feeding (P < 0.05; Table 4). The b* value on day 2 for highland animals was greater with feeding for 0 compared with 2 weeks and for lowland animals, was greatest among lengths for 2 weeks. At 3 days post-slaughter, the b* value was greater for 4 weeks of feeding compared with 0 weeks.

Interactions in hue angle for the hind leg surface between origin and length of feeding were fairly similar at 2 and 3 days post-slaughter (Table 4). Values were not greatly different among lengths of feeding for highland animals. Values on day 2 for lowland animals ranked (P < 0.05) 0 < 2 < 4 weeks although differences were of slightly lower magnitude on day 3. On days 2 and 3, hue angle was greater for lowland than for highland goats (P<0.05), although those for sheep were similar between origins. Chroma for the hind leg surface on day 2 post-slaughter was less for 4 than for 0 weeks of feeding with both origins (P<0.05), although for highland animals, the value for 2 weeks was similar to that for 4 weeks and that for lowland animals was greater for 2 than for 4 weeks (P < 0.05; Table 4). Chroma at 3 days post-slaughter was greater for lowland compared with highland goats (P < 0.05) and was similar between origins for sheep.

Relationships among pH and color measures

Correlations between pH and color measures were similar for all data combined and when conducted separately for each species and experiment. A low correlation existed between pH measured at 15 min and 24 h post-slaughter (r = 0.16; P<0.03). The only significant correlation between pH at 15 min and a color measure involved the L* of the hind leg surface on day 3 post-slaughter (r = 0.15; P < 0.05). There were some significant correlations between pH at 24 h post-slaughter and hind leg surface color measures on days 1 and 2. These variables were day 1 b* (r = 0.20; P < 0.01), day 1 hue angle (r = 0.24; P < 0.01), and day 2 L* (r= -0.19; P < 0.01). Correlation coefficients between 24 h pH and hind leg surface color measures on day 3 were -0.14 (P < 0.03) for L*, -0.31 (P < 0.01) for a*, -0.29 (P < 0.01) for b*, -0.17 (P < 0.02) for hue angle, and -0.32 (P < 0.01) for chroma.

Correlation coefficients between hind leg surface color values on day 1 post-slaughter and values on days 2 and 3 were 0.34 (P < 0.01) and 0.22 (P < 0.01) for L*, 0.48 (P < 0.01) and 0.20 (P < 0.01) for a*, 0.28 (P < 0.01) and -0.04 (P < 0.55) for b*, 0.37 (P < 0.01) and 0.20 (P < 0.01) for hue angle, and 0.33 (P < 0.01) and -0.05 (P < 0.45) for chroma, respectively. Correlations between hind

Table 4. Effects of length of feeding, species (goats vs sheep), and origin (Highland vs Lowland areas) on carcass pH and instrumental color measures.

		Feeding length (wk)				Highland			Lowland				Goats		Sheep			
Item	**Species**	**0**	**2**	**4**	**SE**	**0 wk[1]**	**2 wk[1]**	**4 wk[1]**	**0 wk**	**2 wk**	**4 wk**	**SE**	**H[2]**	**L[2]**	**H**	**L**	**SE**	**Effect[3]**
pH																		
15 min						6.54^{a}	6.55^{a}	6.68^{bc}	6.77^{c}	6.59^{ab}	6.67^{bc}	0.039						
24 h	Goats	6.00^{cd}	5.78^{ab}	6.06^{d}	0.044													
	Sheep	5.74^{a}	5.77^{ab}	5.85^{bc}														
													5.93^{bc}	5.97^{c}	5.85^{b}	5.74^{a}	0.036	
***Longissimus dorsi* cross section (day 0)**																		
L*	Goats					37.0^{ab}	36.5^{ab}	35.2^{a}	39.7^{c}	44.8^{d}	43.3^{d}	0.96						
	Sheep					35.2^{a}	35.9^{a}	36.4^{ab}	37.5^{abc}	38.8^{bc}	37.2^{abc}							
a*	Goats					8.4^{bcd}	11.5^{f}	7.8^{bc}	8.0^{bc}	7.6^{b}	6.1^{a}	0.46						
	Sheep					8.5^{bcd}	9.1^{cd}	9.1^{cd}	9.7^{de}	10.8^{ef}	9.1^{cd}							
b*		10.7^{a}	12.2^{b}	10.5^{a}	0.18								10.6^{a}	11.9^{c}	10.8^{ab}	11.2^{b}	0.21	
Hue angle	Goats					51.7^{bcd}	45.7^{a}	50.4^{bc}	55.0^{d}	60.0^{e}	61.9^{e}	1.48						
	Sheep					49.3^{abc}	53.0^{cd}	49.8^{bc}	48.4^{ab}	48.5^{ab}	49.6^{abc}							
Chroma	Goats	13.8^{b}	15.8^{c}	12.6^{a}	0.32													
	Sheep	13.8^{b}	15.7^{c}	14.0^{b}														
Hind leg surface, L*																		
Day 1	Goats	34.3^{ab}	33.2^{ab}	36.7^{d}	0.53													
	Sheep	33.1^{a}	34.6^{bc}	36.0^{cd}														
						34.6^{b}	32.6^{a}	35.5^{b}	32.8^{a}	35.2^{b}	37.2^{c}	0.53	33.6^{a}	35.9^{c}	34.8^{bc}	34.3^{ab}	0.44	
Day 2	Goats	35.3^{a}	37.5^{bc}	37.6^{bc}	0.49													
	Sheep	36.4^{ab}	36.1^{a}	38.5^{c}														
						34.9^{a}	35.5^{ab}	35.8^{ab}	36.8^{bc}	38.1^{c}	40.3^{d}	0.49						
Day 3		37.7^{a}	36.8^{a}	39.2^{b}	0.40								36.5	39.0	36.2	39.8	0.46	OR
a*																		
Day 1	Goats	8.7^{d}	8.8^{d}	6.5^{a}	0.33													
	Sheep	8.3^{cd}	7.8^{bc}	7.3^{ab}														
						7.0^{ab}	7.8^{b}	7.3^{ab}	10.0^{d}	8.7^{c}	6.5^{a}	0.33	8.2^{b}	7.8^{b}	6.6^{a}	9.0^{c}	0.27	
Day 2						8.7^{c}	8.5^{c}	7.6^{b}	9.4^{d}	9.4^{d}	6.8^{a}	0.30	8.5^{ab}	7.9^{a}	8.1^{a}	9.1^{b}	0.24	
Day 3													8.6	8.4	9.1	9.4	0.20	SP

Table 4. Contd.

b*																	
Day 1	Goats	7.4^{b}	8.2^{b}	6.4^{a}	0.29												
	Sheep	6.1^{a}	8.5^{c}	7.4^{b}													
						4.5^{a}	7.9^{c}	6.1^{b}	9.0^{d}	8.8^{d}	7.7^{c}	0.29	5.8a	8.9d	6.5b	8.1c	0.24	
Day 2						9.1^{bc}	7.7^{a}	8.2^{ab}	8.4^{ab}	9.8^{c}	8.7^{b}	0.36						
Day 3		9.0^{a}	9.6^{ab}	10.0^{b}	0.27								8.8^{a}	10.4^{b}	9.3^{a}	9.6^{a}	0.31	
Hue angle																		
Day 1	Goats					32.0^{a}	37.3^{ab}	36.6^{ab}	45.4^{de}	53.5^{fg}	2.03							
	Sheep					32.1^{a}	54.7^{g}	43.4^{cde}	38.3^{bc}	42.2^{bcd}	46.9^{de}							
Day 2						46.3^{b}	41.8^{a}	47.3^{b}	41.7^{a}	46.0^{b}	52.6^{c}	1.06	43.3^{a}	48.9^{c}	47.0^{bc}	44.7^{ab}	0.86	
Day 3						45.2^{ab}	43.7^{a}	46.9^{bc}	45.0^{ab}	48.8^{cd}	50.4^{d}	1.05	45.3^{a}	50.8^{b}	45.3^{a}	45.4^{a}	0.86	
Chroma																		
Day 1	Goats	11.5^{c}	12.1^{c}	9.3^{a}	0.35													
	Sheep	10.3^{b}	11.7^{c}	10.5^{b}														
						8.4^{a}	11.4^{c}	9.6^{b}	13.5^{e}	12.5^{d}	10.1^{b}	0.35						
Day 2						12.6^{bc}	11.5^{ab}	11.2^{a}	12.6^{bc}	13.6^{c}	11.1^{a}	0.42						
Day 3													12.3^{a}	13.5^{b}	13.0^{ab}	13.4^{b}	0.32	OR

[1]Length of the feeding period. The 0-wk length was 2 d of rest before harvest. [2]H = Highland; L = Lowland. [3]SP = species, OR = origin ($P < 0.05$). Abbreviations are shown when interactions involving these main effects were nonsignificant ($P > 0.05$). [a,b,c,d,e,f,g] Means within rest, species × rest, origin × rest, or species × origin groupings without a common superscript letter differ ($P < 0.05$).

leg surface values on days 2 and 3 post-slaughter were 0.72 ($P < 0.01$) for L*, 0.57 ($P < 0.01$) for a*, 0.57 ($P < 0.01$) for b*, 0.69 ($P < 0.01$) for hue angle, and 0.53 ($P < 0.01$) for chroma.

DISCUSSION

BW and carcass mass

Merera et al. (2009) reported appreciable increases in slaughter BW of highland sheep by resting for 2 or 3 days compared with 1 day. This aspect was not the focus of the present rest experiment. However, 2- and 4-weeks feeding treatments are comparable to those of Merera et al. (2009) with sheep. The ADG in the feeding experiment were much lower for 2 weeks of feeding than observed by Merera et al. (2009). However, as noted previously, these ADG are underestimates of actual values since final BW was determined after an overnight period without feed. Merera et al. (2009) concluded that a 2-week feeding period could be employed with highland sheep to markedly increase carcass weight. Carcass weight in the present feeding experiment of both sheep and goats fed for 2 weeks was also greater than that of animals fed for 0 weeks (that is, rested for 2 days), but as exemplified by a mean ADG of 65 g, this difference was largely attributable to initial BW.

Non-carcass tissues

The skins and hides industry is very important in Ethiopia (Abadi, 2000; Mahmud, 2000). Thus, it is of practical importance that skin mass relative to EBW was greater for sheep than for goats in both rest and feeding experiments. Furthermore, this difference between species was greater for the

lowland than for the highland origin. Skin mass was 1% unit greater for highland compared with lowland goats in the rest experiment and similar between goat origins in the feeding experiment. The small ruminant export industry in Ethiopia has developed in the last decade because of several factors (Merera et al., 2009). The major source of small ruminants for the export market has been from the lowland areas, but the increasing demand is forcing abattoirs to consider highland animals. However, carcasses of highland small ruminants have been thought to have relatively short shelf-life. Thus, with a presumable increase in the proportion of exported carcasses from highland areas compared with the past, yield of skins available for export or use in the domestic leather industry will be affected relatively more for sheep than for goats. Likewise, higher carcass mass relative to EBW in both experiments for lowland than for highland animals indicates that non-carcass tissues available for market will rise with an increasing proportion of exported highland carcasses.

The digestive tract and liver are very metabolically active tissues that can account for a large proportion of energy used for maintenance in ruminants (Ferrell, 1988). Present experiments indicate that species differences in digestive tract and liver mass may contribute to the lower maintenance energy requirement of sheep compared with goats (NRC, 2007). However, the mass of these tissues is also affected by level of feed intake as reflective of 'metabolic workload' (Johnson et al., 1990). Digesta mass relative to EBW also can provide an indication of plane of nutrition. Based on digestive tract, liver, and digesta mass in the rest experiment, it appears that plane of nutrition prior to animal procurement was greater for lowland than for highland goats. This may be a factor contributing to the difference in hind leg surface lightness (that is, L*) between goat origins. Mass of the digestive tract and liver of sheep in the rest experiment does not indicate a similar origin difference in pre-harvest or on-farm plane of nutrition; however, digesta mass was greater for lowland than for highland sheep.

Carcass color

In contrast to the findings of Merera et al. (2009), this study showed that carcasses of goats and sheep from the highland area were darker than those from the lowland area. Also, Merera et al. (2009) suggested that a factor contributing to the lack of difference in lightness between highland and lowland sheep was that the shortest period of rest was 1 day, in regard to shorter rest times possibly used by abattoirs. However, the origin difference was observed in both of the present experiments one with rest for 0, 1, and 2 days and the other with 2 and 4 weeks feeding. Differences in experimental methods might have been involved as well, as Merera et al. (2009) measured color of the surface of the *l. dorsi* muscle trimmed of any fat and connective tissue present and a small amount of surface muscle after a bloom time of 30 min. Also, these authors did not observe differences in carcass L* between rest periods of 1, 2 and 3 days, and feeding periods of 2, 4, and 6 weeks. Conversely, in the present rest experiment, 1 or 2 days of rest increased carcass surface lightness measured on day 3 post-slaughter of goats but not of sheep regardless of origin. Resting of goats before slaughter for 1 or 2 days was necessary for L* to reach levels for sheep that were similar among rest periods of 0, 1 and 2 days. Therefore, it is postulated that the most severe problems of short shelf-life or early darkening of small ruminant carcasses occur with goats given little if any rest and, based on species × origin means, the greatest concern appears warranted for highland goats. Feeding for 4 weeks increased lightness of the carcass surface on day 3 post-slaughter irrespective of species and origin. Although, considering low ADG during the 4-weeks period even though values presented are underestimates of actual ADG on an unshrunk BW basis, it is doubtful that such a practice would be practical.

The most attention has been given to carcass surface lightness assessed by L*. However, hind leg surface a* on day 3 post-slaughter was greater for sheep than for goats in both experiments, indicating a greater degree of redness for sheep. Conversely, species and origin differences in b*, hue angle, and chroma were absent or inconsistent between experiments.

All correlations between pH of the *l. dorsi* muscle at 24 h post-slaughter and color measures for the hind leg surface on day 3 were significant. However, low coefficients indicate relatively little explained variability in carcass color and considerable impact of other factors. As an example, pH at 24 h post-slaughter was less for highland compared with lowland animals rested 0 and 1 day, with values similar between all rest highland treatments and lowland animals rested for 2 days. Likewise, pH for Lowland goats in the rest experiment at 24 h post-slaughter was considerably greater than for other species × origin treatments. Nonetheless, carcass surface L* was lower for lowland than for highland animals.

Based on correlation coefficients, color measures on day 1 post-slaughter were not highly related to color measures on days 2 or 3. Conversely, determinations on day 2 post-slaughter were moderate to highly related to measures on day 3. Nonetheless, magnitudes of correlation coefficients reflect appreciable change during that period of time in factors affecting color.

SUMMARY

Lightness of the carcass surface at 3 days post-slaughter was lower for sheep and goats from the highland than lowland areas of Ethiopia. Lightness of goat carcasses increased by resting for 1 or 2 days compared with 0 day before harvest regardless of origin. A long feeding period

such as 4 weeks increased carcass surface lightness irrespective of species and origin, although there was negligible change in BW during the feeding period.

ACKNOWLEDGMENTS

This experiment was supported by the United States Agency for International Development (USAID)/Ethiopia under agreement number 663-A-00-05-00441-00 for the project entitled Ethiopian Sheep and Goat Productivity Improvement Program. Appreciation is expressed to the Organic Export Abattoir for the excellent assistance provided.

REFERENCES

Abadi Y (2000). Current problems of the leather industry. In: Merkel RC, Abebe G, Goetsch AL (eds) The Opportunities and Challenges of Enhancing Goat Production in East Africa Conference Proceedings, Debub University, Awassa, Ethiopia. pp. 139-142.

CIE (1976). Recommendations on uniform color spaces – color difference equations, psychometric color terms. In: Supplement No. 2 to CIE Publication No. 15 (E-1.3.1) 1978, 1971/(TC-1-3). Commision Internationale de l'Eclairage, Paris, France.

Ferrell CL (1988). Contribution of visceral organs to animal energy expenditures. J. Anim. Sci. 66 (Suppl. 3): 23-34.

Francis FJ, Clydesdale FM (1975). The measurement of meat color. In: Food Colorimetry: Theory and Application. The AVI Publishing Company, Westport, CT. pp. 73-111.

Hunter RS, Harold RW (1987). Uniform color scales. In: The Measurement of Appearance (2nd edn). Hunter Associates Laboratory, Reston, VA. pp. 135-148.

Johnson DE, Johnson KA, Baldwin RL (1990). Changes in liver and gastrointestinal tract energy demands in response to physiological workload in ruminants. J. Nutr. 120: 649-655.

Mahmud A (2000). Development potential and constraints of hides and skins marketing in Ethiopia. In: Merkel RC, Abebe G, Goetsch AL (eds) The Opportunities and Challenges of Enhancing Goat Production in East Africa Conference Proceedings, Debub University, Awassa, Ethiopia. pp. 127-138.

Merera C, Abebe G, Sebsibe A, Goetsch AL (2009). Effects and interactions of origin of sheep in Ethiopia (Highland vs Lowland areas), feeding, and lengths of rest and feeding on harvest measures. J. Appl. Anim. Res. In review.

NRC (2007). Nutrient Requirements of Small Ruminants. Sheep, Goats, Cervids, and New World Camelids. National Academy Press, Washington, DC.

SAS (1990). SAS/STAT User's Guide (Ver. 6, 4th edn, Vol. 2). SAS Institute Inc., Cary, NC.