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Effect of feed restriction on compensatory growth response of young male goats

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Summary

Forty eight 8-month-old male goats were divided into three groups. In each group, eight goats were feed-restricted for 45, 60 or 75 days, and eight goats served as the control. Restricted groups were fed with a maintenance ration, and the control goats were fed with a ration supporting 50 g of daily weight gain. At the end of restriction period, the restricted goats were offered the same ration as the control goats. When the average weight of the 75-day restricted goats approached that of the control, the goats were slaughtered. The carcass, several organs, carcass cuts and dissectible (trimmed) fat were weighed, and the chemical composition of the meat was determined. Feed restriction decreased the proportion in live weight of the dissectible fat, internal fat, liver and testis weight, meat dry matter and fat content, but the proportion of intestinal and splenic weights, and meat protein content were increased. Re-alimentation after 75 days of restriction was associated with a greater daily gain and less internal fat. Other measurements were not different from the control. Data showed that 8-month-old native kids are capable of considerable compensatory growth after 75 days of feed restriction without any deleterious effect on carcass composition.

Key words: Compensatory growth, Goat, Carcass composition, Body components

Introduction

Compensatory (catch-up) growth may be defined as a physiological process whereby an organism accelerates its growth after a period of restricted development usually due to reduced feed intake, in order to reach the weight of animals whose growth was never reduced (Hornick *et al.*, 2000). The periodic feed shortage results in the weight loss of grazing ruminants and is particularly evident in young animals (Ryan, 1990). When cultivated forages are scarce or expensive and feed supplements are not economical, it may be desirable to take advantage of catch-up growth and even incorporate it into normal production system (O'Donovan, 1984; Lawrence and Fowler, 2002).

Animals may respond differently to re-alimentation when nutritional restriction is removed. Extensive studies in sheep and cattle have shown that this variability in the rate of catch-up growth may be influenced by genetic factors, the age at which restriction is imposed, the severity and duration of restriction, the quality of re-alimentation diet and duration of re-feeding (Benschop, 2000; Lawrence and Fowler, 2002). There appears to be a critical period in cattle and sheep from birth to three months of age when nutritional restriction will not trigger a compensatory growth. Following this period, animals can exhibit catch-up growth until they reach maturity (Ryan, 1990).

Compared to cattle and sheep (O'Donovan, 1984; Ryan, 1990; Lawrence and Fowler, 2002), very few studies have been conducted on goats. Salem *et al.* (1989) studied the effects of periodic feed restriction for 5, 10 and 15 days and re-alimentation for 10 days on body weight change, feed digestibility and nitrogen balance in mature Baladi bucks. Sahlu *et al.*

(1999) reported on the feed-intake, body weight change, feed digestibility, blood metabolites and carcass and organ characteristics of 14-month-old Angora wethers at three levels of feed restriction (50, 65, and *ad lib.* intake followed by 41 days of re-alimentation). The effect of feed and water restriction on body weight, digestibility and nitrogen balance of 12- to 15-month-old Sudanese bucks were reported by Ahmed Muna and El Shafei Ammar (2001). The effect of length and severity of feed restriction on body weight, carcass characteristics and several organs of adult female crossbred Nubian goats were studied by Mora *et al*. (1996). Pre-ruminant goat kids, receiving a milk replacer with low solids content showed a compensatory growth that was related to decreased energy requirements for maintenance (Sanz Sampelayo *et al*., 2003). Joemat *et al*. (2004) showed that growth and development of yearling Spanish doelings were slightly less susceptible to periods of low nutrient intake compared with Boer × Spanish doelings. Tovar-Luna *et al*. (2007) studied the effect of moderate feed restriction on energy expenditure by 2-year-old crossbred whether Boer goats and found appreciable changes in metabolism by tissues that highly influenced by nutrient absorption, notably the gastrointestinal tract and liver.

Goats are important grazing ruminants in many countries that face periodic shortages of feed availability in their natural habitat. There are about 25 million goats in Iran which are mainly dependent on natural vegetations and crop residues. Over-grazing is one of the major causes of feed shortage which is exacerbated by recurring drought periods. Most studies mentioned above were performed on mature goats. We were not able to locate published studies with younger goats; therefore, this experiment was conducted to expand our knowledge of catch-up growth in goats by using 8-month-old native male goats.

Materials and Methods

Forty eight native male goats (8-month-old; 15.5 ± 1.5 kg body weight) were used to study the effect of three periods of feed restriction on compensatory growth. The animals were obtained from one of the flocks established for preservation and breeding of local livestock in Dashtestan area, Bushehr province, Iran. The goats were randomly allotted into three groups of 16 animals, and were fed in groups. They were initially fed for 30 days (stabilization period) with a mixed ration which was calculated to supply the maintenance requirement as well as a daily gain of 50 g (NRC, 1981). Eight goats in each group were fed for 45, 60 or 75 days (feed restriction period; FRP) with a maintenance diet that supplied 0.78 Mcal metabolizable energy (ME) and 32 g total protein per kg dry matter (DM). This ration contained 320 g alfalfa hay, 135 g wheat straw, 2.5 g common salt and 3 g of a vitamin-mineral mixture. The other goats of each group served as the control and were fed with a ration that supplied the requirements for maintenance as well as 50 g daily gain. At the end of each restriction period, three or four goats from control and the feed-restricted group were slaughtered for data collection, and the remainder was fed with the control diet until the average body weight of each restricted group approached those of its control (re-alimentation period; RAP). The re-alimentation periods for the three restricted groups were 136, 121 and 106 days, respectively. At the end of re-alimentation periods the goats were slaughtered for data collection.

The stabilization and re-alimentation diets were made of alfalfa hay, wheat straw, barley grain, soybean meal, wheat bran, common salt and a vitamin-mineral mixture. Each kg (dry matter) of these diets supplied 1.15 to 1.27 Mcal ME and 46 to 52 g total protein. The amount fed was adjusted at two-week intervals after weighing the goats. Water was freely available at all times. During the RAP, one goat from each of three control groups and one goat from one of the previously restricted groups had to be omitted from the experiment due to coccidiosis or respiratory problems. Water and feed were removed for 12 h before slaughter. On the day of slaughter, the animals were weighed (final or slaughter weight) and a jugular blood sample was taken for determination of serum cholesterol (Rifai *et al*., 1999), creatinine and urea nitrogen (Newman and Price, 1999). The blood sample was centrifuged at 3000 rpm for 15 min, and the serum was kept at -20ºC until analysis.

The goats were slaughtered according to the local practices (Zamiri and Izadifard, 1994). The weight of internal organs were recorded and internal fat (pericardial, perinephric, pelvic and gastrointestinal) was removed and weighed. Cold carcass weight was determined after 24 h at 4°C. Fat depth over carcass was measured at the cross section of the 12th and 13th thoracic ribs at 4 points and the values were averaged as a measure of subcutaneous fat (SCF) depth. The width and depth of the eye muscle (*Longissimus dorsi*) was measured on both sides of the carcass between the 12th and 13th ribs. The cross section of the eye muscle was traced on a nylon sheath and the area was then measured by using a planimeter.

The right side of each carcass was cut into the leg, shoulder, back, neck, thoracic wall and abdominal wall. The cuts were dissected into trimmed meat, fat and bone. Trimmed meat and fat from the right side of the carcass were minced and mixed thoroughly, and samples were kept at -20°C until analyzed (AOAC, 1975) for dry matter, ether extract (fat), and nitrogen contents (expressed as crude protein).

Statistical analysis

Data were analyzed by using the GLM procedure of the SAS for windows program on a personal computer (SAS, 1996). Initial body weight was used as covariate in data analysis. For each period of the study, the effect of feed restriction or re-alimentation was compared with its respective control. Percentage data were transformed into arcsine $\sqrt{X}$ before analysis. Mean and standard deviation of original data are reported in the paper. Pearson's correlation coefficient of several blood metabolites with meat protein, fat and dry matter was calculated using the data for all goats.

Results

The mean initial weight of goats in various feeding regimens was not significantly different and ranged from 14.9 to 15.6 kg. As expected, average daily gain (ADG) and live weight of the feed-restricted groups decreased as the period of feed restriction was increased (Table 1). During FRP, the ADG of all control groups was positive and the feed-restricted groups lost between 3.3 to 6.6% of their initial weights. During RAP, ADG of the 45- and 60-day feed restricted goats approached those of their control ($P>0.05$), but the 70-day feed restricted goats had a significantly greater ADG than their control groups ($P<0.05$). Feed-conversion ratio (FCR) was not statistically analyzed due to group feeding, but during RAP, feed-conversion ratio of the 70-day restricted group was 13.3 vs. 32.3 for the control. The FCR of other groups were numerically very close to their control (data not tabulated). Similar to changes in live weight, feed restriction resulted in a decrease in the cold carcass weight, but dressing percentages were not significantly affected by the treatment (Table 1).

Feed restriction decreased the percentage of trimmed fat in the carcass (Tables 2 and 3), especially in the abdominal wall (Table 2). Re-alimentation resulted in increases in percentage of trimmed fat in most carcass subdivisions which approached that of the control animals, except for the shoulder of the 70-day restricted group that contained proportionately less trimmed fat than its control (Table 2). The percentage of trimmed meat (lean) decreased non-significantly but the percentage of bone was increased as the duration of feed restriction increased (Table 3). The area of the cross section of the *Longissimus dorsi* muscle (LD area) was decreased by feed restriction, and increased to the control values upon re-alimentation. Similar trends were noted for the LD width and depth (Table 3).

Subcutaneous fat (SCF) depth was reduced to zero level even after 45 days of feed restriction, but was increased upon re-alimentation (Table 4). The amount of internal fat and its percentage in slaughter weight were also reduced significantly by feed restriction. Upon re-alimentation, the percentage of internal fat of 75-day restricted goats was significantly less than (more than 20%) its control group (Table 4). Almost similar trends were noted for the fat removed from individual organs.

Table 1: Effect of feed restriction and re-alimentation on live weight change, carcass weight and dressing percentage (mean ± SD) of young male goats during feed-restriction period (FRP) and re-alimentation period (RAP)

	Duration of feed restriction before re-alimentation					
	45 days		60 days		75 days	
	Control	Restricted	Control	Restricted	Control	Restricted
No. of goats						
FRP	7	7	7	8	7	8
RAP	7	7	7	8	7	8
No. of days in period						
FRP	45	45	60	60	75	75
RAP	136	136	121	121	106	106
Final weight (kg)						
FRP	16.6±1.3	15.0±1.4	16.4±1.2	14.5±1.1**	16.7±1.3	14.4±1.2*
RAP	19.5±1.4	17.9±2.1	18.5±2.7	17.5±1.6	19.1±2.0	19.0±0.7
Average daily gain (g)						
FRP	22±40	-11±22	26±16	-14±5**	19±14	-10±21*
RAP	21±5	21±7	19±13	25±10	19±11	43±5*
No. of goats slaughtered						
FRP	4	4	4	4	4	4
RAP	3	3	3	4	3	4
Slaughter weight (kg)						
FRP	16.8±1.3	14.0±1.3*	16.3±1.5	14.2±1.7**	16.7±1.1	13.0±1.2**
RAP	19.7±1.4	17.9±2.1	18.5±2.7	17.8±1.5	19.1±2.0	19.0±0.7
Cold carcass weight (kg)						
FRP	6.6±0.6	5.2±0.5*	6.2±0.7	5.2±0.7*	6.1±0.5	4.9±0.5*
RAP	7.5±0.8	6.8±0.7	7.1±0.9	6.6±0.7	7.1±0.6	7.4±0.2
Dressing percentage						
FRP	39.3±0.5	38.1±0.7	39.1±0.6	37.2±1.9	38.2±1.1	37.8±0.5
RAP	38.9±1.4	38.7±1.1	39.4±1.4	38.5±1.2	38.1±0.7	39.4±0.3

*(P<0.05), **(P<0.01) significantly different from the respective control within each group

Table 2: Effect of feed restriction and re-alimentation of goats on trimmed fat (% of cut weight) of individual carcass parts (mean ± SD) during feed-restriction period (FRP) and re-alimentation period (RAP)

	Duration of feed restriction before re-alimentation					
	45 days		60 days		75 days	
	Control	Restricted	Control	Restricted	Control	Restricted
Leg						
FRP	3.1±0.9	2.4±0.9	3.3±0.4	1.4±0.7*	2.7±0.4	1.3±0.8*
RAP	3.4±0.2	3.6±1.1	3.1±0.7	3.6±0.2	4.2±1.1	3.3±0.6
Shoulder						
FRP	4.7±1.2	2.6±0.5**	4.1±1.3	1.8±1.1*	3.4±1.6	1.1±1.5
RAP	5.8±0.1	4.9±0.8	4.4±1.3	5.2±0.7	5.3±0.5	4.3±0.5*
Back						
FRP	4.0±0.7	2.0±0.8*	3.7±0.8	1.1±2.2	3.7±1.4	0.4±0.7**
RAP	3.9±0.1	4.0±0.6	3.9±0.3	3.0±0.8	4.5±0.8	3.4±0.6
Neck						
FRP	2.4±0.7	0.5±0.7*	3.2±0.6	0.8±0.9*	2.2±0.2	1.2±0.4*
RAP	2.8±0.6	2.3±1.1	2.4±0.4	0.9±0.7	2.3±0.4	1.1±1.2
Thoracic wall						
FRP	11.7±2.1	4.0±4.5*	6.3±4.9	2.2±1.9	8.8±3.1	1.9±1.4*
RAP	11.3±4.5	9.5±5.6	14.0±5.5	13.3±6.7	16.5±5.1	9.8±1.6
Abdominal wall						
FRP	21.5±3.5	0.0±0.0***	20.3±10.4	0.0±0.0***	14.7±13.6	0.0±0.0***
RAP	18.8±1.6	17.0±7.7	19.0±10.2	15.6±2.5	20.0±11.7	14.3±6.4

*(P<0.05), **(P<0.01), ***(P<0.001) significantly different from the respective control within each group

Feed restriction resulted in decreased dry matter and fat (ether extract) and increased protein (crude protein) percentage of the carcass soft tissues (trimmed meat plus fat), but significant differences with the control were found after 60 and 75 days of restriction (Table 5). The differences disappeared after re-alimentation. Blood serum parameters (cholesterol, creatinine and urea nitrogen) were not significantly affected by feed restriction and re-alimentation (Table 5). Correlation between serum cholesterol and meat parameters were small (r = 0.10) and non-significant. Serum creatinine was negatively correlated with meat protein (r = -0.36; P<0.05) and positively with meat fat (r = 0.37; P<0.05). Serum urea nitrogen was positively correlated with meat protein (r = 0.35; P<0.05) and negatively with meat fat (r = -0.39; P<0.01) and dry matter (r = -0.34; P<0.05).

Table 6 shows the changes in the weights of several organs expressed as the percentage of slaughter weight. Although the absolute weight of the empty intestines and spleen decreased in 75-day restricted goats, their proportion in the live weight

Table 3: Effect of feed restriction and re-alimentation on carcass physical composition (% of cold carcass weight) and *Longissimus dorsi* muscle (LD) of goats (mean ± SD) during feed-restriction period (FRP) and re-alimentation period (RAP)

	Duration of feed restriction before re-alimentation					
	45 days		60 days		75 days	
	Control	Restricted	Control	Restricted	Control	Restricted
Carcass trimmed meat (%)						
FRP	66.5±2.2	65.4±3.1	59.6±6.3	57.5±4.9	64.4±6.3	61.2±3.5
RAP	65.3±3.8	66.3±1.0	67.5±3.9	67.0±3.1	66.0±0.7	66.7±2.9
Carcass trimmed fat (%)						
FRP	6.1±1.1	2.4±0.9**	4.9±1.5	1.4±0.4***	4.8±1.3	1.2±0.3***
RAP	6.1±0.7	5.6±1.7	6.5±2.1	6.3±1.1	7.0±1.7	5.1±0.6
Carcass bone (%)						
FRP	27.4±0.9	32.2±2.8*	35.5±6.7	40.0±4.4	30.8±5.5	37.6±4.0
RAP	28.6±5.0	28.1±0.8	26.0±4.6	26.7±2.7	27.0±1.6	28.2±2.1
LD width (cm)						
FRP	3.45±0.40	3.03±0.20	3.19±0.40	2.75±0.20**	3.52±0.30	2.76±0.10*
RAP	3.81±0.10	3.67±0.20	3.68±0.30	3.58±0.20	3.69±0.20	3.56±0.20
LD depth (cm)						
FRP	1.90±0.18	1.50±0.22	1.85±0.24	1.59±0.02***	1.84±0.07	1.55±0.08**
RAP	1.86±0.07	1.77±0.21	1.78±0.14	1.70±0.11	1.88±0.05	1.93±0.16
LD area (cm^2)						
FRP	5.4±0.5	4.0±0.5*	5.5±1.2	3.9±0.5***	6.1±0.6	3.7±0.5**
RAP	6.3±0.5	5.9±0.5	6.1±1.0	5.7±0.8	6.1±0.6	6.2±0.7

*(P<0.05), **(P<0.01), ***(P<0.001) significantly different from the respective control within each group

Table 4: Effect of feed restriction and re-alimentation of goats on subcutaneous fat depth (cm) and internal fat as a percentage of slaughter live weight (mean ± SD) during feed-restriction period (FRP) and re-alimentation period (RAP)

	Duration of feed restriction before re-alimentation					
	45 days		60 days		75 days	
	Control	Restricted	Control	Restricted	Control	Restricted
Subcutaneous fat depth						
FRP	0.31±0.13	0.0±0.0*	0.37±0.13	0.0±0.0*	0.37±0.16	0.0±0.0*
RAP	0.56±0.7	0.34±0.11**	0.44±0.24	0.28±0.3	0.56±0.11	0.44±0.05
Pericardial fat						
FRP	0.07±0.01	0.01±0.03*	0.08±0.02	0.01±0.02**	0.08±0.03	0.0±0.0***
RAP	0.11±0.01	0.09±0.03	0.06±0.04	0.02±0.02	0.10±0.04	0.05±0.02
Perinephric fat						
FRP	0.15±0.12	0.05±0.04	0.14±0.06	0.02±0.05*	0.18±0.10	0.02±0.01*
RAP	0.20±0.02	0.20±0.07	0.29±0.19	0.20±0.07	0.24±0.11	0.15±0.05
Pelvic cavity fat						
FRP	0.16±0.06	0.01±0.02**	0.11±0.03	0.01±0.03*	0.31±0.15	0.07±0.07**
RAP	0.44±0.02	0.08±0.03**	0.30±0.07	0.06±0.01**	0.16±0.01	0.05±0.03**
Gastrointestinal fat						
FRP	1.5±0.1	0.5±0.3*	1.1±0.3	0.4±0.2*	1.4±0.7	0.5±0.2*
RAP	2.1±0.5	1.9±0.4	2.7±0.9	2.2±0.3	1.7±0.1	1.4±0.2
Total internal fat						
FRP	1.8±1.1	0.6±0.3*	1.4±0.3	0.4±0.3**	1.9±0.2	0.6±0.1**
RAP	2.8±0.4	2.3±0.5	3.3±0.1	2.4±0.4	2.2±0.2	1.7±0.3*

*(P<0.05), **(P<0.01), ***(P<0.001) significantly different from the respective control within each group

Table 5: Effect of feed restriction and re-alimentation on chemical composition (%) of carcass soft tissue and blood serum attributes (mg/dl) in goats (mean ± SD) during feed-restriction period (FRP) and re-alimentation period (RAP)

	Duration of feed restriction before re-alimentation					
	45 days		60 days		75 days	
	Control	Restricted	Control	Restricted	Control	Restricted
Composition of carcass soft tissue:						
Dry matter						
FRP	38.5±4.5	31.3±3.0	34.1±1.6	26.1±0.7***	35.5±1.4	26.2±0.7***
RAP	32.5±1.5	36.3±3.0*	39.3±3.9	35.1±4.2	34.7±1.9	33.4±0.5
Crude protein						
FRP	19.7±1.3	20.6±1.3	20.7±1.2	20.7±0.6	20.9±0.3	22.0±0.3**
RAP	19.9±0.9	20.8±0.9	20.3±0.6	20.3±0.9	20.4±0.5	20.5±1.4
Crude protein (DM basis)						
FRP	51.7±6.4	66.5±10.4	60.8±5.4	79.7±1.2**	59.2±2.9	84.3±3.2***
RAP	61.1±0.1	57.7±7.0*	51.8±5.3	58.4±6.3	58.5±1.8	61.3±4.9
Ether extract						
FRP	16.9±4.7	9.8±4.1	11.6±2.3	3.4±0.6***	12.1±1.4	2.2±0.6***
RAP	11.1±0.7	14.1±4.2*	18.0±4.2	13.6±4.1	13.2±1.6	12.0±1.9
Ether extract (DM basis)						
FRP	43.4±7.7	30.5±9.8	33.9±5.3	13.1±2.0***	34.2±2.8	8.3±2.2***
RAP	34.3±0.8	38.4±8.0*	45.4±5.9	38.1±7.3	38.1±2.4	36.0±5.1
Blood attributes:						
Serum cholesterol						
FRP	20.5±1.3	22.5±0.9	30.5±12.2	22.0±1.8	22.2±4.7	18.5±1.7
RAP	29.0±1.0	31.0±7.8	22.3±2.5	24.5±1.3	23.3±2.1	32.5±9.9
Serum creatinine						
FRP	0.87±0.05	0.92±0.12	0.97±0.15	0.87±0.22	0.85±0.05	0.67±0.12
RAP	0.90±0.01	1.00±0.20	0.83±0.05	0.82±0.05	0.90±0.10	0.87±0.05
Serum urea nitrogen						
FRP	16.2±1.2	17.0±1.8	16.0±2.7	17.7±2.2	16.5±1.2	18.7±0.5
RAP	17.6±0.5	17.0±2.0	17.0±1.0	16.7±1.4	16.6±2.0	16.5±1.3

*(P<0.05), **(P<0.01), ***(P<0.001) significantly different from the respective control within each group

Table 6: Effect of feed restriction and re-alimentation on organ weights (% of slaughter live weigh) in goats (mean ± SD) during feed-restriction period (FRP) and re-alimentation period (RAP)

	Duration of feed restriction before re-alimentation					
	45 days		60 days		75 days	
	Control	Restricted	Control	Restricted	Control	Restricted
Liver						
FRP	1.6±0.1	1.4±0.1	1.7±0.2	1.7±0.3	1.8±0.1	1.5±0.1**
RAP	1.8±0.3	2.1±0.2	1.7±0.1	1.8±0.1	1.9±0.4	1.9±0.3
Intestines (Empty)						
FRP	3.6±0.5	3.9±0.4	3.6±0.2	4.3±0.7	4.2±0.1	4.5±0.1*
RAP	2.6±0.2	3.2±0.5*	2.4±0.5	2.5±0.3	3.2±0.7	3.2±0.4
Head						
FRP	8.5±0.8	9.3±0.5	8.4±0.4	10.0±0.8**	8.4±0.3	8.8±0.4
RAP	8.3±0.2	8.3±0.9	8.8±0.7	8.1±0.4	7.5±0.8	7.5±0.4
Testis and associated tissues						
FRP	0.63±0.06	0.43±0.10*	0.56±0.13	0.38±0.02**	0.64±0.09	0.44±0.18*
RAP	0.78±0.12	0.81±0.13	0.74±0.09	0.65±0.06	0.76±0.08	0.74±0.07
Spleen						
FRP	0.15±0.03	0.13±0.01	0.13±0.03	0.13±0.02	0.12±0.01	0.17±0.01**
RAP	0.12±0.02	0.13±0.02	0.15±0.05	0.11±0.01	0.14±0.03	0.15±0.05

*(P<0.05), **(P<0.01) significantly different from the respective control within each group

increased. Liver weight, both absolute (data not reported) and its proportion in the live weight (Table 6) was decreased significantly in the goats that were feed-restricted for 75 days. Testis weight, both absolute and as a proportion of the live weight was smaller for all periods of feed restriction. Feed restriction was generally associated with decreases in the absolute weight of the skin, stomach, stomach content, and kidneys, but their proportion in the live weight was not significantly affected by feed restriction or re-feeding. The weights of heart and lungs and their proportion in the live weight were not influenced by feed restriction and re-alimentation (data not shown).

Discussion

Compensatory indices after re-alimentation of the 45-, 60- and 75-day restricted goats were 0.06, 44 and 95%, respectively. In contrast to the findings of Drouillard *et al.* (1991) in cattle, our data concerning the increased growth rate during re-alimentation of goats which were feed-restricted for a longer duration (75 days) are in agreement with other data in cattle and sheep (Ryan *et al.*, 1993; Yambayamba *et al.*, 1996a; Kamalzadeh *et al.*, 1998a, b, c) indicating that increased duration of feed restriction is likely to increase the rate of growth after re-alimentation (Ryan, 1990). Feed restriction which decreases the weight or minimizes the weight gain could result in higher growth rate that also lasts for a longer period (Ryan *et al.*, 1993; Sahlu *et al.*, 1999).

Decreased maintenance cost, increased feed intake, increased efficiency of growth, genetic background, and in some instances increased digesta load have been implicated as the key mechanisms in the compensatory growth phenomenon (Ryan, 1990; Benschop, 2000; Hornick *et al.*, 2000; Sanz Sampelayo *et al.*, 2003; Joemat *et al.*, 2004). Feed intake data could not be statistically analyzed due to group feeding but compared with the control group, the restricted goats consumed 13% less feed during FRP and 2% more feed during RAP. Upon re-alimentation, there was a 60% improvement in the overall FCR of the 75-day restricted goats compared with their control goats. The decreased feed intake or the non-significant effect of the duration of restriction in some studies may be due to variation in intensity, and duration of restriction and re-alimentation (Ryan, 1990). The increase in feed intake during re-alimentation may be due to increases in the size of the digestive system, increase in energy requirement for maintenance, increased protein deposition, and modification of the endocrine system (Hornick *et al.*, 2000).

Increased growth rate during RAP, also observed in this experiment with goats, could be a consequence of increased efficiency of protein and energy utilization, increased feed intake, decreased maintenance requirement, increased gut fill and decreased heat production during FRP and its continuation during RAP (Fox *et al.*, 1972; Graham and Searle, 1979; Carstens *et al.*, 1989; Yambayamba *et al.*, 1996a). It has been suggested that contribution of reduced maintenance may continue for up to 110 days in cattle and sheep (Ryan, 1990). The present data on goats seem to support this view.

Increase in the size of gastrointestinal tract and the amount of gut contents may account for all or portion of the weight gain during compensatory growth although it does not appear that changes in digestibility is a key factor involved in compensatory growth (Cumby, 2000; Weekes, 2000). In the present experiment, feed restriction caused a decrease in the absolute weight of the empty stomach and intestines, and while proportional weight of stomach was the same during FRP and RAP, the proportion of intestines in the live weight was higher after 75 days of feed restriction. It is believed that visceral organs have different growth and metabolic rates compared with other organs and the feed quality and quantity affect their growth (Kamalzadeh *et al.*, 1998c).

Several studies in other ruminants have reported decreases in the absolute and relative size of the liver (Reid *et al.*, 1980; Ferrell *et al.*, 1986; Aziz *et al.*, 1993; Yambayamba *et al.*, 1996b). Liver weight, both absolute and as a percentage of the live weight, was significantly decreased in goats that experienced the longest duration of feed restriction (75 days). Similarly, in the study of Mora *et al.* (1996) with Nubian does the proportion of liver in the live weight was affected by the feeding level. Reduction in the liver weight of sheep was related to a decrease in oxygen consumption by the liver and hepatic blood flow (Burrin *et al.*, 1989). It has recently been shown that moderate feed restriction of Boer wether goats resulted in appreciable changes in metabolism of the liver and gastrointestinal tract (Tovar-Luna *et al.*, 2007).

Our data indicate that decrease in the size of gastrointestinal tract was proportionately smaller than that for the liver. The lowered maintenance requirement of these organs persists during RAP until protein is fully replenished in these organs.

Due to increased protein deposition needed to replenish these organs, fat to protein ratio of the body decreases (Ryan *et al*., 1993). The present data in goats point to the liver as a more important organ in decreasing the metabolic rate of the animal during feed shortage. Wester *et al*. (1995) reported that livers of lambs were replenished in two days, but according to Ryan *et al*. (1993) the livers of cattle and sheep were replenished in 90 days.

Data on changes in the gut contents in cattle are contradictory (Hogg, 1991; Yambayamba *et al*., 1996b) although Hogg (1991) concluded that increased gut fill could make a substantial contribution to the apparent increase in live weight gain. Sahlu *et al*. (1999) also concluded that a substantial amount of increase in body weight of 14-month-old Angora wethers during the first 20 days of the 41-day RAP was due to increased gut fill. In our experiment, the proportion of stomach contents in live weight was not affected upon re-alimentation.

Proportional changes in weights of head and skin of goats were in line with data in lambs (Kamalzadeh *et al*., 1998c). The proportions of body weight in wool and pelts were lower than the control lambs whereas the feet, head and visceral organs were higher. Spleen size was reduced in cattle (Seebeck, 1967; Yambayamba *et al*., 1996b), and Seebeck (1967) suggested that since the function of the spleen is to store blood for release under stressful conditions, the smaller spleen size might have been related to concomitant reduction in blood weight. In our experiment, spleen size was increased proportionately during feed restriction, and this finding does not support the interpretation of the data found in cattle.

The absolute weight of kidneys was smaller for the longest duration of feed restriction (75 days), but the proportion of live weight in kidneys was not affected by treatments. The effect of feed restriction on kidney size in other studies has been variable and it may be related to the level of restriction (Yambayamba *et al*., 1996b).

Ryan *et al*. (1993) studied the compensatory growth of cattle and sheep that were restricted for 80 to 90 days which compensated for the first three months following re-alimentation. Besides liver and gastrointestinal tract, feed restriction affected other tissues as well; however, there were species differences. The cattle lost weight from the digestive tract, lungs, liver and gained weight in their head and feet. The weight of their heart, hide, bones and meat did not change. The sheep also lost weight in their livers, digestive tracts, meat and hides. The weights of lungs, feet, head and bones remained unchanged during feed restriction. In the present experiment, heart and lung weights were not affected by the treatments. Testis weight, absolute and proportional, decreased significantly in feed-restricted goats, and recovered after re-alimentation. Similarly scrotal circumference of sheep was also decreased by feed restriction (Kamalzadeh *et al*., 1998b). Vleurick *et al*. (2000) showed in Belgian Blue bulls that the onset of puberty was delayed in feed-restricted animals until they were refed. The contemporary rise of testosterone levels during refeeding may also be important for compensatory growth in intact young males. The goats in the present experiment were between 7- to 8-month-old when they were subjected to feed restriction. The cold carcass weights of the 45-, 60- and 75-day restricted goats were about 19, 16 and 21% lighter than that of their control groups, respectively. This reflected changes in their live weight. Similar trends were noted for carcass joints. As with data in steers and lambs, the dressing percentage of goats was not affected in the present experiment.

Feeding level can affect the carcass composition (Butler-Hogg, 1984; Murphy and Loerch, 1994; Murphy *et al*., 1994) and body fat can be used as an immediate source of energy when feed intake is not adequate (Aziz *et al*., 1992). When growth rate is reduced, there is a coordinated decrease in tissue turnover, but some tissues react more than others. Fat depots follow an order of depletion during feed restriction, opposite to the direction of their development (Hornick *et al*., 2000). In general, early maturing parts (head, feet and visceral organs) have higher priority for the use of available nutrients in blood and are less affected than the late maturing parts by feed restriction. Upon re-alimentation, the responses are mainly related to their reactions during restriction; the organs which are most affected and have the greatest retardation, respond quicker than those that are less affected. Some adipose compartments, such as SCF, may be mobilized more easily than others (Hornick *et al*., 2000). In the present experiment, feed restriction was associated with significant decreases in the proportion of fat in various fat depots. The largest decrease in the fat content was found for the SCF and pericardial fat followed by perinephric, pelvic cavity, and gastrointestinal fat depots. There were also variations in response of fat in various carcass parts; abdominal fat being the most sensitive fat depot followed by the fat in back, thoracic wall, shoulder, leg and neck. Feed restriction for 75 days resulted in almost complete disappearance of the SCF depth, and total internal fat was reduced to about 30% of the control groups. Re-alimentation increased the contents of fat in various depots; however, after re-alimentation of the 75-day restricted goats, the proportions of total internal fat and pelvic cavity fat were 20 and 70% less than their control goats, respectively.

In the study of Yambayamba *et al*. (1996b) with beef heifers, the lower proportion of total side fat during feed restriction was associated with a higher proportion of side bone but similar proportion of side muscle after re-alimentation. Price (1977) found similar trend in restricted steers. Increase in the proportion of bone was also reported by Verbeek (1961) and Seebeck and Tulloh (1968). Proportion of carcass trimmed fat decreased in feed restricted goats, but proportion of lean was decreased non-significantly. Increased proportion of bones was noted for the 45-day ($P = 0.05$), 60-day ($P>0.10$), and 75-day ($P = 0.10$) restricted goats. Both protein and fat are utilized during feed restriction. Initially proteins are mobilized which lasts for some days until a new equilibrium is reached, paralleled by a decrease in basal metabolism. Then fat is mobilized dependent on the severity of feed restriction, whereas the protein pool is conserved as much as possible. During severe and prolonged feed restriction, the initial switch from protein to fat mobilization is initially observed but is rapidly followed by combined fat and protein losses (Hornick *et al*., 2000). Therefore, longer durations of feed restriction might also lead to decreases in lean meat in goats. It is noteworthy that LD area of the 75-day restricted goats was 39% smaller than that in the control goats.

It is generally accepted that during re-alimentation, more protein is deposited initially but further gains in body weight are due to increased fat (Rompala *et al*., 1985; Wright and Russel, 1991); however, the growth of various tissues is dependent on breed and age of the animal (Hornick *et al*., 2000). Feed restriction of goats was associated with an increase in protein and decreases in dry matter and fat (ether extract) content of the carcass soft tissues but upon re-alimentation, the fat content was similar to the control goats. Feed restriction of steers (Murphy and Loerch, 1994) and lambs (Murphy *et al*., 1994) was also associated with a decrease in fat and increases in protein and water contents. Mora *et al*. (1996) studied the effects of two periods (18 and 36 weeks) and two levels (60 and 80% vs. 100%) of feed restriction on non-lactating, non-pregnant, adult Nubian does. Chemical composition of soft tissue was not affected in that experiment. The discrepancy between our data and those of Mora *et al*. (1996) may be explained by the age (degree of maturity) of animals, and the period or severity of feed restriction (Aziz *et al*., 1992). Sahlu *et al*. (1999) reported that the level of feed intake during the restriction period did not affect the body composition of 14-month-old Angora wethers that were restricted for 40 days followed by 41 days of re-alimentation.

We did not observe any effects of feed restriction and re-alimentation on serum levels of cholesterol, creatinine and urea nitrogen. Sahlu *et al*. (1999) reported that severity of feed restriction was linearly related to plasma urea levels during re-alimentation of Angora wethers; restricted animals had lower plasma urea concentration. Plasma creatinine during the restriction period decreased with the increasing level of feed intake and then increased whereas during RAP, the plasma creatinine concentration increased as the level of feed intake during the restriction phase increased. In the rat, there was a decrease in amino acid oxidation during re-alimentation which is the cause of lowered plasma urea during the initial phase of re-alimentation (Carreira *et al*., 1996).

Feed restriction of 8-month-old native male goats for 75 days followed by re-alimentation increased the dry matter and fat contents at equal live weights, but decreased the protein content of the carcass soft tissues. Feed restriction for 75 days and re-alimentation had no deleterious effect on carcass composition, and at the same time resulted in a decrease in the proportion of internal fat.

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