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Assessing Nutrient Requirements and limits to Production of the Camel under its Simulated Natural Environment

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ABSTRACT

A series of calorimetric and energy balance experiments were conducted on female dromedary camels. First, these studies were designed to determine the nutrient requirements for maintenance and growth. Five female dromedaries were fasted for four days and then fed three different levels of feeding during three successive periods. Digestive trials were conducted and heat production of animals was estimated by indirect calorimetry during each period. Retained energy was regressed against metabolizable energy intake and the energy requirements for maintenance (MEm) were estimated to average 314 kj/kgW$^{0.75}$. This was representing about two thirds of the available energy indicating that the dromedaries utilized fed energy for maintenance with an efficiency of 73%, comparable to sheep; and for growth with an efficiency of 61%, better than sheep and cattle.

In the second part of this study and in order to simulate the natural desert environment of the dromedary camel. The energy balance under conditions of heat exposure, reduced water and feed intakes was monitored in order to precisely define the limits to production of camels when fed at maintenance energy requirements. The heat exposure did not affect the feed intake or the basal metabolism of the camel. Under dehydration conditions, camels were able to maintain their appetite up to 15% of body weight loss and to allow their basal metabolism to decline in order to maintain a positive energy balance. Fasted for 2 days, camels showed less body reserves mobilization and yet some met of the nutrients required for fasting metabolism through fermentation products of the digestive tract. The results of the present studies may allow the development of management strategies that would improve camel production without any further degradation of the fragile ecosystem of arid and semi-arid regions.

Key words: Nutrient requirements, Maintenance, Growth, Energy, Camel.

INTRODUCTION

Through evolution, dromedary camels have specially adapted to arid environments and developed physiological mechanisms to face heat stress, dehydration (Guerouali *et al.,* 1994a) and shortage in nutrients (Guerouali *et al.,* 1997). These physiological adaptations to the arid conditions of the desert may affect the appetite and the energy balance of the camels. It is reported that in extreme cases of limited natural vegetation, the camel not only decreases its feed intake, but also reduces its metabolic rate (Dahlborn *et al*., 1992). Under these circumstances, production is adjusted to energy intake, which in part, explains the supposed poor production of the camel in arid zones. There have been few investigations on feeding standards for the camel and assessment of its nutritional requirements remains very empirical and often extrapolated from studies done on cattle of tropical regions.

The present study was designed first, to estimate the nutrient requirements of the dromedary at maintenance when using the indirect calorimetry. In the second part of this study and in order to simulate the natural desert environment of the dromedary camel. The energy balance under conditions of heat exposure and reduced water intake was monitored, in order to precisely define the limits to production of camels when fed at maintenance energy requirements. When considering the camel's feeding system in arid zones, based on grazing large areas with little vegetation, animals often go through periods of fasting for few days in search of new grazing areas. For this reason, the third part of the study was designed to investigate the metabolic adjustments developed by the camel, compared to sheep, to face these periods of fast.

MATERIALS AND METHODS

Nutrient requirements experiment

Five healthy female camels (8 to 10 year old) were used over four successive periods with different levels of feeding. The diet consisted of 66% barley grains and 34% wheat straw and was fed at 0 fasting heat producion (FHP), 0.5 (P1), 1 (P2) and 2 (P3) time maintenance energy requirements (Mem) of sheep (397 kj of ME per kgW0.75, INRA 1978). During each period of the study, a pre-sacked diet was offered to the animals, 3 days prior and 7 days during the digestive trials at 9 am daily. The uneaten feed was removed and weighed after 24 hours. Feces were removed from the fecal collection bag daily for 7 consecutive days weighed and 10% was dried and added to composite dry aliquot for each animal. Fecal and diet dry matter was determined by drying the samples at 105 ^{o}C for 24 hours. The gross energy contents of the feeds and feces were determined on one g pelted samples in an adiabatic bomb calorimeter (Parr 1241). The ME intake was estimated from the DE intake by using the following ME/DE ratios: 0.82, 0.83 and 0.88 in P1, P2 and P3, respectively (INRA, 1978). An indirect calorimetry system of an open circuit type was used to measure the oxygen consumption for 24 hours per animal per period. Heat production (HP) was estimated by using the equation of McLean (1972):

$$HP\ (kcal/d) = (O_2\ In\text{-}Out) \times Flow\ (STPD) \times 4.89$$

FHP was also estimated by measuring gaseous exchanges of each dromedary on day 4 of a fast. Retained energy (RE) was determined by subtracting HP from ME intake. Linear regression equations were computed between RE and ME intake in order to determine the Mem and ME efficiency.

Heat stress and dehydration experiment

The same five camels were used in two experiments dealing with heat stress and dehydration. During the heat stress experiment, animals were exposed to an ambient temperature of 20^{o}C in a climatic chamber for the whole days of two weeks (P1). And the temperature was increased to 40 ^{o}C for 12 hours per day and reduced to 20^{o}C for the rest of the day for another two weeks (P2). The dehydration experiment consisted of 7 days of normal hydration as a control period (D1) followed by 27 days of dehydration (D2) allowing the animals to lose 20% of body weight, then 3 days of rehydration (D3) to reach the water intake experienced in the control period. For the two experiments, the camels received 2 kg of barley grains, 1 kg of wheat straw and 50 g of vitamins and minerals. Except for the dehydration period, camels had free access to drinking water. Digestive trials were conducted and oxygen consumption of the camels was measured once in P1, P2, D1, D3 and three times in D2 (at 10%, 15% and 20% of body weight loss).

Food deprivation experiment

Five adult female camels and six adult ewes were used in this study. The experiment was divided into three successive periods (Control, Fasting and refeeding). During the control period (P1) of 7 days, camels were fed 2 kg of barley grains and 1 kg of lucerne hay corresponding to the energy requirements for maintenance. While ewes were fed .4 kg of barley grain and .2 kg of lucerne hay corresponding to maintenance energy requirements (Guerouali *et al*., 1991), Both species had free access to water. During the second period, the ewes and camels were fasted for 2 days but access to water was maintained. Immediately after the fast, camels and ewes were fed the same amount of feed experienced in the control period for 4 days (refeeding period). Digestive trials were conducted for 7 days in the control period and 4 days in the refeeding period. Animal heat production (continuous 24 hours O_2 consumption measurement) was determined on the last day of the control period, on the second day of fast and on the fourth day of the refeeding period using indirect calorimetry system with a chamber for camels and a hood for sheep (McLean, 1972).

RESULTS AND DISCUSSION

Nutrient requirements experiment

Diet composition and digestibility variations with feeding level are presented in table 1. In the first and second periods, the amount of food offered to the dromedaries was totally consumed. However, in the third period all the barley grain offered was consumed, but about 25% of the wheat straw was refused. Consequently, barley grains constituted about 66% of the diet in P1 and P2 and 72% in P3. This may explain the higher value for digestible energy observed in P3 (63%) compared to values determined in P1 and P2 (61%). Metabolizable energy intake, total heat production and retained energy variations with the level of feeding are presented in Table 2. Fasting heat production was estimated from the oxygen consumption of the animals on the fourth day of the fast and averaged 213±15 $kJ/kgW^{0.75}$/day. In D'man sheep fasted for four days, HP averaged 245±32 $kJ/kgW^{0.75}$ (Guerouali, 1990). The FHP of dromedaries determined in the present study compares more closely with the FHP of adult sheep (240 $kJ/kgW^{0.75}$; ARC, 1980) than of adult cattle (319 $kJ/kgW^{0.75}$; Van Es, 1972).

Table 1. Diet ingredients and digestibility variations with the level of feeding.

Periods	FHP	P1	P2	P3
Diet ingredient:				
Barley grains (kg)	0	1.0	2.0	4.0
Wheat straw (kg)	0	0.5	1.0	2.0
Vitamins and minerals supplement[a] (g)	0	50.0	50.0	50.0
Energy digestibility (%)				
Mean	-	61.0	60.9	62.8
SD	-	4.1	3.5	3.1

[a]Vitamins and minerals supplement was composed of 18% Calcium, 15% Sodium Chloride, 12% Phosphorus, 2% Magnesium, 1% Sulfur, 1.5% Trace Elements, 0.5% Vitamins and 50% excipient.

All the dromedaries showed an increase in HP in response to the increase in feed intake, with 38% more heat produced from FHP to P2 and 28% more from P2 to P3. Retained energy was regressed against ME intake for different sets of data and the linear regression equations obtained are presented in Table 3. These equations indicate, when assuming RE = 0, that Mem averaged 296±16 kJ/kgW$^{0.75}$. This value is higher than that (218 kJ/kgW$^{0.75}$) reported by Schmidt-Nielsen *et al.,* (1967). However, it should be noted that in the Schmidt-Nielsen study, heat production was determined by measuring respiratory gases with mask when the animals were under heat stress conditions.

Table 2. Metabolizable energy intake and total heat production variation with the level of feeding[1].

Periods of study	FHP	P1	P2	P3
Metabolizable energy intake (kj/kgW$^{0.75}$)				
Mean	0	162	321	584
SD	0	16	32	44
Total heat production (kj/kgW$^{0.75}$)				
Mean	213	272	300	386
SD	15	21	20	39
Retained energy (kj/kgW$^{0.75}$)				
Mean	213	-110	21	198
SD	15	21	20	39

[1]Mean and the standard deviation of five dromedaries used in the study.

Different values of the efficiency of utilization of ME intake above and below maintenance requirements were obtained through regression equations, indicating that ME was used below maintenance with an efficiency of 73% (km = .73) and above maintenance with an efficiency of 61% (kf = .61). This km value is close to those calculated from energy balance studies in sheep and cows fed a mixed diet of the same metabolizability (ARC, 1980). However, the kf value is higher than most values (kf varied between 41% and 56%) found in the literature (Blaxter, 1974; Garrett et al, 1976). With the high value of kf, it seems likely that the dromedary utilizes nutrients for body tissue gain better than true ruminants.

Table 3. Linear regression of retained energy against metabolizable energy at different levels of feeding.

Data Considered	Regression Equation	Coefficient (R^2)	MEm kj/MBS[a]
-FHP, P1, P2, P3	RE = .70ME-214.9	.97	307.1
-FHP, P1, P2,	RE = .73ME-214.1	.95	300.2
-P2, P3	RE = .61ME-170.4	.89	279.4

[a]maintenance energy requirements expressed in kJ per metabolic body size ($kgW^{0.75}$)

Heat Stress and dehydration experiment

When camels were exposed to 40 °C for 12 hours per day, water intake was increased by an average of 200% and the ratio between water intake and dry matter intake reached three times the ration observed at 20°C. The increase in water intake was expected in order to replace the water loss used to dissipate the additional heat load through evaporative cooling. Camels did not show any significant change in feed intake and digestibility under heat stress conditions (table 4). A small but not significant reduction in heat production (an average of 14%) was found under heat stress leading to a slight increase in energy balance.

According to Wilson (1989), the heat loads from the high temperatures and from direct radiation are intense in desert areas and the animal may compensate by reducing its food intake and being generally less active. Some species, including sheep, goats and cattle have reductions in food intake ranging from 10% to 50%. In contrast to the later species, the present experiment showed that the food intake and heat production of the camel exposed to heat stress did not decline significantly. This is one of the major indications that the camel is relatively productive in extremely hot areas whereas species showing reduction in food intake and metabolic rate under heat stress are not adapted and are unable to maintain any production.

Table 4. Effect of heat stress on water and feed intake, dry matter digestibility and energy balance in camels.

Item	Temperature of exposition	
	20°C	40°C/20°C
Average feed intake (kg/ Animal/d)	3.0	2.8
Barley grains Intake	2.0	2.0
Wheat straw Intake	1.0	0.8
Average water intake (L/d)	5.1^{a}	15.9^{b}
Dry matter digestibility (%)	60.9	61.3
Average energy balance (MJ/d)	4.3	6.8
Metabolizable energy intake	23.9	23.7
Total heat production	19.6	16.9

^{a,b} Means in the same row with different superscripts differ significantly ($P<0.05$).

Under ambient temperature averaging 20°C, the dehydration experiment lasted 27 days in order to reach a reduction in body weight of up to 20% (table 5). Camels lost body weight with an average of 0.74% per day which was lower than 2%, 4% and 6% loss in goats, sheep and cattle respectively, exposed to day/night temperature of 40°C/25°C (Siebert & MacFarlane, 1975). Water intake, averaging 1.3% of body weight during normal hydration period, increased to 19% within a few minutes of rehydration, allowing the animals to recover approximately all the weight lost during the 27 days of dehydration. Resistance to dehydration and drinking large amounts of water are physiological adaptive mechanisms that the animal has developed to survive in an undesirable dry environment.

Table 5. The effect of dehydration and rehydration on feed intake, dry matter digestibility and energy balance in camel.

	Level of dehydration (%)				
Item	0	10	15	20	0
Body weight variations (%)	100	90.3	85.3	80.2	99.3
Water intake (L/d)	4.0	--	--	--	56.6
Dry matter intake (kg/d)	3.0[a]	3.0[a]	2.2[b]	1.7[c]	2.6[a]
Barley grains	2.0	2.0	1.6	1.2	1.8
Wheat straw	0.96	0.98	0.6	0.5	0.8
Dry matter digest (%)	61.0[b]	65.3[b]	74.2[a]	73.7[a]	75[a]
Energy balance (MJ/d)	1.5	6.9	4.1	1.5	3.8
ME	23.9	25.5	21.4	15.4	25.4
HP	22.4[a]	18.6[b]	17.3[b]	13.9[c]	21.6[a]

[a,b,c] Means in the same row with different superscripts differ significantly ($P<0.05$).

Feed intake was maintained at 10% of dehydration but reduced by 27% and 44% at 15% and 20% of dehydration, respectively. During rehydration, feed intake was 13% less than that experienced in the normal hydration period (Table 5). Dry matter digestibility increased with the level of dehydration with an average of 18% increase at 15%, 20% dehydration and during the rehydration period. The reduction in feed intake was probably related to a reduction in saliva flow (Wilson, 1989) and the passage rate of the digesta through the alimentary tract in dehydration was partly explained by the increased proportion of barley in the ratio (66% vs 73%). However, two other causes were reported in the literature. One involves a reduction of urine outflow in dehydrated camels which increases the nitrogen recycling into the rumen and more urea is supplied to the rumen microorganisms for fermentation. The other cause relates to the reduction in the passage rate of digesta through the alimentary tract, allowing more time for fermentation in the rumen and digestion and absorption in the gut.

Total heat production decreased during dehydration by 17%, 23% and 40% at 10%, 15% and 20% levels of dehydration, respectively. During rehydration, HP increased to the level observed in the normal hydration period. It was shown that in the normal hydrated camel fed maintenance energy requirements, a reduction by 50% in the level of intake induced a decline in heat production by only 10% (Guerouali *et al.*, 1994b). Consequently, the reduction in heat production (40% at 20% dehydration) can not be totally explained by the reduction in the level of feeding. But, considerations of water conservation are important in dehydrated camel. So maybe a reduction in water turnover and in evaporative cooling observed in dehydrated camels (Schmid-Nielsen, 1964) were responsible for the reduction in heat production. This allowed the camels to maintain themselves in positive energy balance throughout the dehydration period. Therefore, body energy was not mobilized to meet the energy requirements of the animals and probably all the body weight loss during dehydration was just water.

Food deprivation experiment

During the refeeding period, perturbations in feed and water intakes were observed for both species, corresponding to the post-fast anorexia described in other species (Harris et al. 1986), but were more pronounced in sheep, compared to camels. Dry matter digestibility, averaged 62% in camels and 68% in ewes during the control period (Table 6). It seems likely that the diet offered was better digested by ewes than camels and the difference was probably due to lower efficiency of mastication and rumination in camels since a part of the barley grains offered in the ration was excreted in the feces.

During the two days of fast, a 5% reduction in body weight was observed in camels in comparison with 9% in sheep (Table 6) and 10% reported in cattle (Phillips et al, 1991). Desert goats fasted for 4 days showed 11.6% reduction of their body weight (Ali et al, 1984).

Table 6. Water intake, feed intake, digestibility and body weight with respect to fasting period in camels and sheep.

	Water Intake (L/24hr)	Feed Intake (kg/24hr)	DM digestibility (%)	Body wt. (kg)
CAMELS				
Feeding	5.2±1.22	3.0±0.0	61.6±3.8	300±34
Fasting	2.4±0.4	-	-	285±31
Refeeding	3.5±0.4	2.81±0.2	-	289±32
SHEEP				
Feeding	1.78±0.4	0.6±0.0	67.5±6.3	35.6±4.4
Fasting	1.18±0.5	-	-	32.5±4.5
Refeeding	1.63±0.41	0.47±0.11	-	34.0±4.6

The low rate of body weight loss observed in fasted camel may indicate the superiority of this animal in digesta retention and/or limitation in body reserves mobilization. Methane production, averaged 1.36 liters/kg 0.75/24 hours (Table 7) and was comparable in both species. However, it declined markedly by 72% in camels and 93% in ewes during the fasting period then increased progressively during the refeeding period without reaching the levels observed at the control period.

Changes in methane production in dairy cattle with respect to 2 days fast were also reported by Bouvier (1977) showing a pattern of changes comparable to the one observed in sheep. The higher methane production observed in camels after 2 days of fast is in favor of more digesta retention in the digestive tract to allow fermentation. This result may confirm the lower rate of body weight loss found in camels compared to sheep. During the refeeding period, the observed perturbations in feed and water intakes may explain the limited methane production in both species.

The respiratory quotient of animals, representing the ratio between O_2 consumption and CO_2 production, averaged 0.99 and was comparable for both species in the control period (Table 7).

Table 7. Methane production, respiratory quotient and total heat production during feeding, fasting and refeeding periods in camels and sheep.

	Methane prod. (L/kgw $^{0.75}$/24hr)	O_2 Cons. (L/kgw $^{0.75}$/24hr)	CO_2 prod. (L/kgw $^{0.75}$/24hr	Resp. quotient (L/kgw $^{0.75}$/24hr	Total heat prod. (kj/kgw $^{0.75}$/24hr)
CAMELS					
Feeding	1.4±.1	14.8±1.6	14.8±1.2	1.0±.03	303±33
Fasting	0.4±.1	10.8±1	9.6±1.1	0.9±.07	220±13
Refeeding	0.9±.1	12.6±1.1	12.8±1.0	1.1±.06	259±29
SHEEP					
Feeding	1.4±.3	17.5±1.9	17.2±1.8	0.98±.1	380±41
Fasting	0.1±.1	14.8±2.1	11.7±1.8	0.8±.06	302±2
Refeeding	0.9±.2	19.7±2.9	16.7±2.8	0.9±.11	403±62

The ratio was reduced to 0.89 in camels and 0.79 in sheep, which may indicate that camels were still deriving some of their nutrient requirements from fermentation products while sheep utilized their body reserves to meet the required nutrients for maintenance during the fasting period.

In another study with camels, sheep and cattle fasted for 5 days, Wensvoort *et al*., (1996). It showed that camels had low rates of increase in serum NEFA and higher glucose levels compared to sheep and cattle. It was concluded that camels seem to do better than sheep and cattle in controlling their lipolytic and gluconeogenic rates in order to prevent the pathological state of ketosis after a period of fast. In the refeeding period, the respiratory quotient value returned to the amount experienced during the control period for camels, but remained lower for sheep after 4 days of feeding, which may show the rapid metabolic adjustments in camels compared to sheep. Heat production averaged 303 kJ/kgw$^{0.75}$ in camels and 380 kJ/kgw$^{0.75}$ in ewes when fed at maintenance energy requirements during the control period, indicating that the metabolic rate in camels is about 20% lower than in sheep. After 2 days of fast, camels showed more reduction in energy expenditures than sheep (27% VS 20%). After 4 days of refeeding, heat production reached the amount experienced in the control period for ewes but was 15% lower for camels. These data on energy expenditures may demonstrate that camels use feeds with better efficiency and when fasted, they mobilized less body reserves.

CONCLUSION

Fasting heat production of camel averaged 213kJ/kgw$^{0.75}$. Heat production increased with the level of feeding. Retained energy was regressed against metabolizable energy intake and the energy requirements for maintenance (at zero energy gain) was estimated to average 296kJ/kgw$^{0.75}$ which is 20% and 40% lower than sheep and cattle respectively. Different estimates of the efficiency of utilization of metabolizable energy for maintenance and gain were obtained, indicating that camels used ME for maintenance with an efficiency of 73% (km = 0.73), comparable to sheep, and for gain with an efficiency of 61% (kf = 0.61), better than sheep.

No change in food intake, digestibility or heat production of camels, which may indicate that this animal is well adapted to the heat and can be productive in an arid environment. Under water deprivation, camels were able to maintain their appetite, to show some improvement in feed digestibility and to allow their metabolic rate to decline in order to save energy and water of the body. These metabolic adjustments kept the animals under a positive balance throughout the dehydration period.

Camels fasted for 2 days showed less body weight loss and were able to maintain fermentation and meet part of the nutrients required for fasting metabolism through fermentation products. Camels were able to develop digestive and metabolic adjustments in order to suffer less from the fast.

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