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Metabolisable energy and protein requirements of the Arabian camel (*Camelus dromedarius*)

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Summary

Camels are browsing herbivores, evolved with the capacity to utilise fibre-rich diets. Under normal feeding conditions, their feeding behaviour is affected by season as they feed on shrubs and trees during the dry season and shift to ground grasses and forbs after substantial rainfall during the wet season. Such feeding behaviour enables them to select the nutritious parts from a variety of vegetations to meet their nutrient requirements. However, when camels are intensively managed and hand-fed in yards, nutritionists face the challenge of providing them with the quantity and quality of feeds that are most suited for their system. This is mainly due to a lack of knowledge about the nutrient requirements of camels and the impacts of intensive nutritional management systems on their feeding behaviour.

Few studies are available on the nutrient requirements of camels and requirement tables, similar to those of other livestock, are not available. Two studies were selected from the literature for the purpose of calculating metabolisable energy and protein requirements for camels. These studies reported calorimetric and balance data of metabolisable energy and protein requirements for maintenance and the efficiencies with which dietary metabolisable energy was utilised for maintenance and production. This article seeks to generate some requirement estimates based on reliable experimental values. Metabolisable energy and protein requirements for maintenance, body gain and milk yield were calculated and presented in tables for use by nutritionists. Each section contains an introductory information to justify and explain the reasons behind doing this work and how each value was calculated. Further testing (field-based animal feeding trials) is required in order to verify the reliability of these estimates.

Keywords: Arabian camel, *Camelus dromedarius*, camelids, metabolisable energy requirements, protein requirements.

Background

Camelids, new world (llama, guanaco, alpaca, vicuna) and old world (dromedary and bactrian camels), evolved as browsing herbivores with the capacity to utilise fibre-rich feeds. They have evolved with a compartmental stomach that holds and ferments feeds. The digestion processes in their compartmental foregut are carried out by a vast number of diverse microbial populations, mainly bacteria, protozoa, fungi and archaea. The symbiotic relationship between these microbes and camelids offers benefits to both, but also presents several challenges of different levels of complexity. The microbes enjoy the stable physiologic conditions of the compartmental stomach with a pH close to neutral (5.5-6.5), optimal temperature for their survival and reproduction (39–40 °C), osmotic pressure near that of the microbial cell, oxygen-free conditions, and continuous supply of nutrients and removal of fermentation end-products. In return, these microbes degrade and ferment dietary fibre, mainly cellulose, hemicellulose and proteins, excluding cell wall proteins, and produce fermentation products that are useful to the host animal.

Microbes also synthesise essential amino acids and vitamins, contribute to the health and the immune system of the host animal, and detoxify some of the toxic food constituents. This is why camelids are able to feed on trees and shrubs of the desert and mountains that are rich in anti-nutritional compounds, particularly those containing high levels of tannins and often avoided by other herbivores.

Digestion processes in the forestomach

Digestion of carbohydrates

Structural carbohydrates (cellulose and hemicellulose), which are components of the plant cell wall and the main constituents of the camelids' natural diet, are broken down to simple sugars, mainly glucose, xylose and fructose, then fermented to volatile fatty acids (VFAs). Acetic, propionic and butyric are the main VFAs produced as a result of the fermentation processes. These VFAs are by-products and not required by the microbes but, under normal feeding conditions, they supply the host camelids with vital energy precursors that are readily metabolised by the body tissues to meet their energy needs. These VFAs are absorbed through the wall of the compartmental stomach into the portal blood and utilised by different animal tissues as energy sources. Other carbohydrates such as starch and sugars will be hydrolysed and fermented at a much faster rate than structural carbohydrates to simple sugars, and then fermented to VFAs. The rapid production of VFAs due to feeding high levels of starch-rich diets may lead to their accumulation in the compartmental stomach and cause acidosis. It is therefore important to supply adequate fibre to maintain normal gut function and control feed intake to prevent the risk of acidosis. Camelids are highly susceptible to acidosis.

Structural Carbohydrates (cellulose & hemicellulose) → Simple Sugars → VFAs

Starch → Maltose & Isomaltose → Glucose → VFAs

Digestion of proteins

Proteins contained in the diet are traditionally estimated in term of crude protein (CP), which represent total nitrogenous compounds, including the true proteins (TP) and non-protein nitrogenous compounds (NPN). True proteins are polymers of polypeptides that are made up of amino acids. True proteins comprise about 80% of the CP in natural forages, grains and protein supplements. True protein is broken down to peptides then amino acids which are deaminated, releasing the amino group of the amino acid, to produce ammonia. NPN compounds, such as nitrate, are rapidly hydrolysed to ammonia (NH_3) and then converted to ammonium (NH_4^+), which is a more stable form of nitrogen than NH_3 in the forestomach.

True Proteins → Peptides → Amino Acids → NH_3 → NH_4^+

Non-protein Nitrogenous Compounds (NPN) → NH_3 → NH_4^+

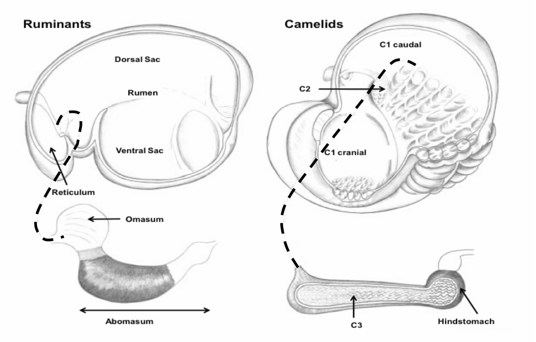

Figure 1. The compartmental forestomach of the ruminants (left) and the camelids (right), after Lechner-Doll, et al. 1990; Sketched by Ms. Kate Andrews (PhD student UQ)

In the compartmental stomach (Figure 1), part of the liberated NH_4^+ is utilised by the microbes for the synthesis of essential and non-essential amino acids to build their own cellular proteins and part is absorbed through the stomach wall and transported to the liver where it is converted to urea via the urea cycle and excreted in urine. Some of the produced urea is recycled and enters the foregut via saliva or diffuses through the wall. Recycling of urea in camelids is known to be efficient in comparison with ruminant animals especially when nitrogen supply is low (Wardeh, 2004) or deprived of water (Mousa et al., 1983). However, due to the extensive degradation of dietary protein in the compartmental stomach, wastage will be inevitably high. For these reasons, nitrogen retention in the camelids is estimated to be low, in the order of 14.6% of total nitrogen intake. As a result of the degradation and re-building of proteins in the compartmental stomach, dietary proteins are remodelled and the amino acid profile of the proteins that enter the intestines bear little relationship to that supplied in the diet. It is important to mention here that microbial protein is relatively of a fixed amino acid profile despite the variable foregut conditions. Also, in comparison with preformed dietary proteins such as that of soybean meal, microbial protein is of an inferior quality in terms of its amino acid profile.

The microbial proteins contained within the microbial cells, together with the undegraded dietary proteins and endogenous protein, pass to the second largest compartment of the camelids' compartmental stomach (C3) and then to the small intestines where they undergo enzymatic digestion by the animal enzymes.

It is important to acknowledge that the camelids' system is similar in principle to that of ruminants, and we are dealing with two systems (i.e., the microbial system and the camel system) that are integrated in one. It is also important to understand that when we are feeding the camelids, we are primarily feeding the microbes in their foregut. In return, the symbiotic microbes supply the host with energy, amino acids and other essential nutrients. Nutritionists are also required to consider the losses associated with the fermentation processes of the foregut and to try to minimise them. These losses include energy in the form of heat of fermentation, energy of survival and reproduction of the microbial population, and gasses such as carbon dioxide and methane. Nitrogen losses are mainly in the form of urea that is derived from deamination and oxidation of amino acids and in sweat. Minimising these losses would make the camelids' system more efficient and reduce the negative impact of the animal systems on the environment.

Designing diets for camelids

The challenges facing nutritionists are to design economic diets that provide optimal conditions to increase animal productivity while maintaining animal health and minimising wastage. When designing such diets for camelids, it is important to carefully select the energy and protein sources, in order to synchronise the supply of energy and nitrogen to maximise microbial protein synthesis and decrease losses. Starches from different cereal grains differ in their rate and extent of fermentability. Similarly, proteins from different sources have different rates and extents of degradation. This is a function of protein type, outflow rate of digesta from the compartmental stomach, the composition of the microbial community and the availability of energy and other nutrients to the microbes. For good quality proteins such as soybean meal protein, which has a degradability value around 65% as measured in ruminants, it would be beneficial to consider partial protection to prevent excessive degradation, minimise wastage, and ensure maximum supply of amino acids to the intestine.

Camelids may also have higher demands for amino acids to satisfy their higher gluconeogenesis, the synthesis of glucose in the liver from amino acids, pyruvate, propionate and L-lactate, and glycogenesis (Emmanuel, 1981; Wensvoort et al., 2004). The extra demand for glucogenic amino acids is expected to be higher for racing and lactating camelids, particularly under conditions when protein supply is limited. The additional amounts of amino acids required to meet the increased demand is a function of intensity and duration of the exercise in racing camels, and the level of production for dairy and growing animals. Thus, it is advisable to supply additional amounts of amino acids from quality protein sources, such as that of the rumen-protected soybean meal, in order to bridge the gap between supply and demand for optimal performance. The benefits would be increasing nitrogen retention and decreasing urea production.

Nutrient requirements of camels

Energy requirements

The metabolisable energy (ME) system will be used in this paper and estimates of energy requirements will be expressed in SI unit for energy, the megajoule (MJ). In practice, the ME of feeds is derived from the apparently digestible energy (DE) after allowing for gaseous and urine losses. Gaseous losses are important in foregut fermenters such as camels' as a considerable proportion of feed energy is lost, particularly in the form of methane. For ruminant animals (i.e., cattle, sheep and goats), a fixed value for total losses of energy in urine and gasses is applied (i.e., 0.19) allowing the calculation of ME from DE to be: ME = 0.81 DE (MAFF, 1987). Digestible energy can be calculated from knowledge of energy intake in feed and energy excreted in faeces. A digestion experiment which will allow total collection of faeces and measurements of intakes is the standard technique used.

This paper utilises data derived from a series of calorimetric and energy balance experiments (Guerouali and Wardeh, 1998). Regression analysis was employed by these researchers to estimate metabolisable energy requirements for maintenance (MEm) using ME intakes and the amounts of energy retained in body tissue. Their estimate of MEm was 0.314 MJ per kg $BW^{0.75}$, which represented about two thirds of the ME intake (73%) from diets consisting of barley grain (66%) and wheat straw (34%) fed at different levels (Guerouali and Wardeh, 1998). In their work, the efficiency at which dietary ME was utilised for gain (K_g) was estimated to be 61%, a value considered to be higher than those reported for cattle and sheep. Using the reported value of 0.314 MJ per $kg^{0.75}$ leads to reasonable estimates of MEm but still need to be verified by feeding trials (Table 1). The MEm is a function of body weight and the relationship between the two variables is linear (R^2 = 1.0, Figure 2).

A regression approach was also followed by Farid et al. (1990), which led to an estimation of MEm by regressing intake against body weight changes as 0.374 MJ per kg $BW^{0.75}$. Their estimates are slightly higher than estimates based on respiratory chamber fasting metabolism values (0.314 MJ per kg

$BW^{0.75}$) by Guerouali and Wardeh (1998). However, after allowing for energy-protein interaction, estimates for maintenance are 0.435 MJ per kg $BW^{0.75}$ (Farid, 1995).

When compared with cattle, camels clearly show lower MEm requirements (Figure 3), and hence lower allowances (Figure 4). The lower energy requirements offer camels a survival advantage over other domestic animals such as cattle under the harsh arid desert environment.

Table 1. Daily metabolisable energy requirements for maintenance (MEm) of the Arabian camel (*Camelus dromedarius*). Estimates include an additional 10% for minimal activity.

Body weight (kg)	**MEm (MJ per day)**
300	24.9
350	27.9
400	30.9
450	33.7
500	36.5
550	39.2
600	41.9

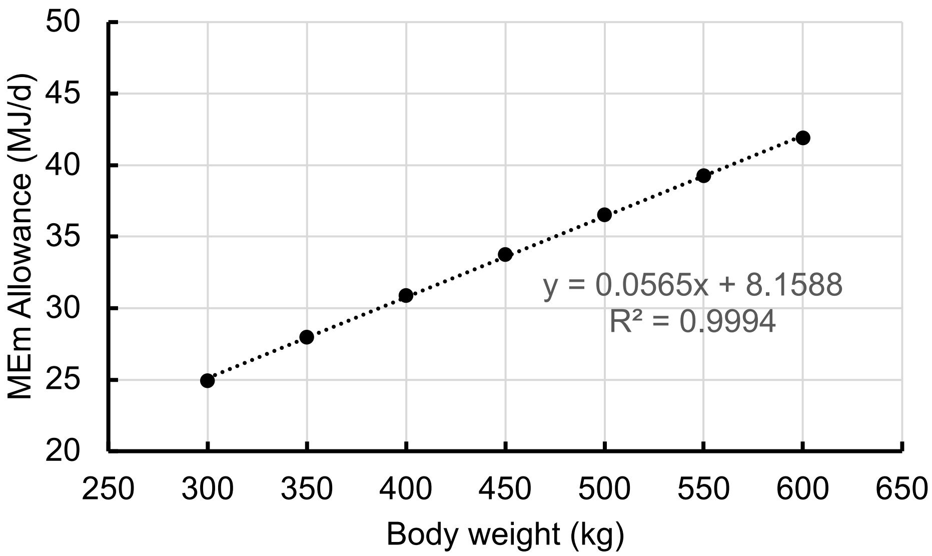

Figure 2. The relationship between body weight of camels (kg) and metabolisable energy requirements for maintenance (MEm, MJ per day).

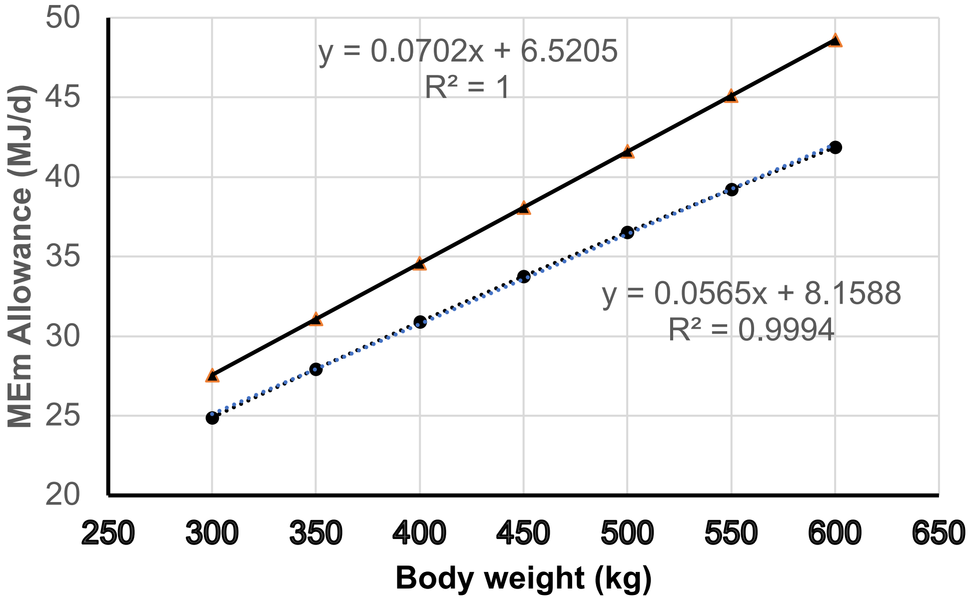

Figure 3. Metabolisable energy requirements for maintenance (MEm) of camels (dotted line) and cattle (solid line), relationship with body weight (kg). MEm for cattle was calculated using the equation: FM (MJ/d) = 5.67 + 0.061W, where W is liveweight in kg (MAFF, 1987). A 5% safety margin and 10% for minimum activity was added. FM= fasting metabolism, which is a measure of the NE requirements. Efficiency of utilisation of dietary ME for maintenance (K_m) is assumed to be 0.72.

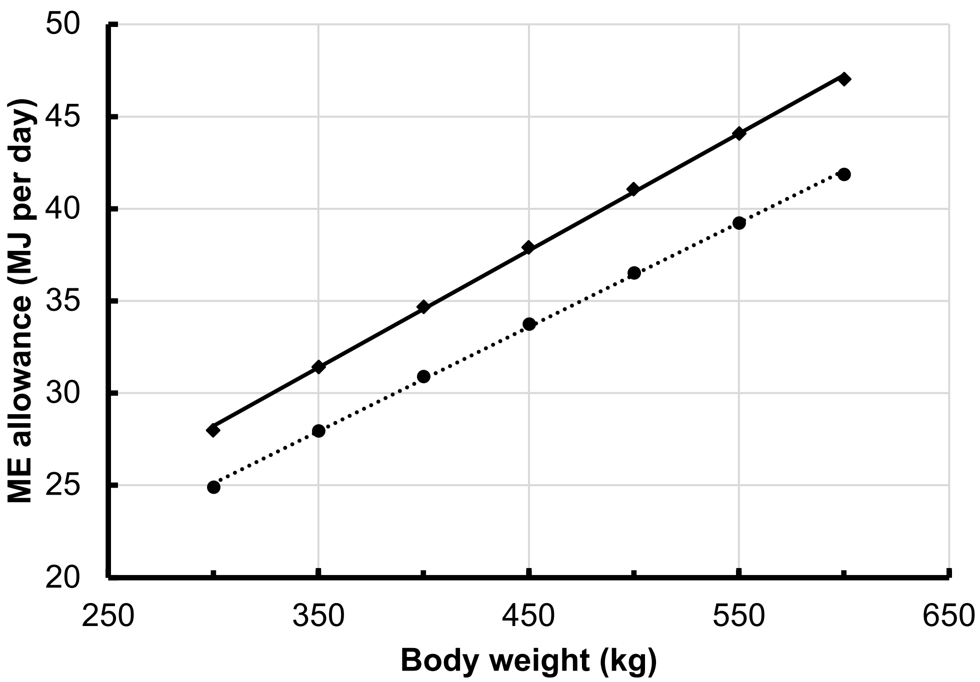

Figure 4. Metabolisable energy allowances for maintenance (MEm) of camels, relationship with body weight (kg). Data adopted from Guerouali and Wardeh (1998), dotted line; Farid et al. (1990), solid line.

Energy requirements for weight gain

The daily metabolisable energy requirements for gain (MEg) can be estimated if the amount of liveweight gain (LWG), the energy value of the gain (EV*g*) and the efficiency at which ME is utilised for gain (K_g) are known. Guerouli and Wardeh (1998) estimated the efficiency of utilisation of ME for gain (K_g) in camels to be 0.61. This value is relatively high compared to estimates reported for cattle, which vary from about 0.30 to 0.60 as M/D varies from 7 to 14 MJ per kg DM (MAFF, 1987). Little information is available on the chemical composition of camel meat to allow direct calculations of its energy content. Reported data came from analyses of a specific muscle (i.e., *longissimus thoracis*) such as that of Kadim et al. (2006) and Shehata et al. (2011). Such an approach excludes the biggest mass of fat deposition in the hump and other parts of the carcass, which are important parts of the metabolic pool. As a result, energy estimates based on specific muscles underestimate the energy value of the gain and hence the energy required to achieve that gain. If the chemical composition of the longissimus thoracis muscle is considered to be (g/kg): 710 g moisture, 214 g crude protein, 64 g fat, and 11 g ash (Kadim et al., 2006), the energy value of this muscle would be 7.7 MJ per kg. However, this muscle is not representative of the whole carcass or the liveweight gain (LWG). If we consider the efficiency for utilisation of ME for body gain (K_g) to be 0.61 (Guerouali and Wardeh, 1998). However, k_g varies depending on the concentration of metabolisable energy in the diet (M/D) which is expressed in MJ per kg DM. MAFF (1987) suggested the use of the equation kg = 0.0435 M/D for calculation and accepted the use of 0.435 value for feedlot cattle and roughage and concentrate feeding systems. As a compromise, the metabolisable energy requirement for gain (MEg) is considered to be 40 MJ per kg LWG (Joyce et al., 1974; MAFF, 1987). This value corresponds to an energy value for the gain of 17.4 MJ, which is equivalent to 2.26 times that of the energy value for the camel's longissimus thoracis muscle. A review of body growth in camels showed wide variation, which is attributed to a number of genetic and environmental factors (Kadim and Mahgoub, 2013). Iqbal et al. (1999) reported an average daily gain for calves (males and females) from birth to six months of age under intensive and traditional systems to be 0.79 kg (ranged between 0.72 and 0.86 kg). Bakheit et al. (2017) reported that calves raised under a semi-intensive system grew faster than calves raised under the traditional system up to six months of age (0.535 vs 0.317 kg). At this stage, and in the lack any estimates on EVg at different ages and different amounts of gain, the value 17.7 MJ used for beef cattle will be adopted here and the efficiency with which dietary ME is utilised for gain K*g* = 0.43. Accordingly, the dietary ME requirements for gain (0.1–1.0 kg/d) is calculated, added to MEm and presented in Table 2.

Table 2. Metabolisable energy requirements for growing and mature camels

Body weight (kg):	100	150	200	250	300	350	400	450	500	550	600
MEm required (MJ/d):	10.9	14.8	18.4	21.7	24.9	27.9	30.9	33.7	36.5	39.2	41.9
Daily gain, kg											
0.10	14.9	18.8	22.4	25.7	28.9	31.9	34.9	37.7	40.5	43.2	45.9
0.20	18.9	22.8	26.4	29.7	32.9	35.9	38.9	41.7	44.5	47.2	49.9
0.30	22.9	26.8	30.4	33.7	36.9	39.9	42.9	45.7	48.5	51.2	53.9
0.40	26.9	30.8	34.4	37.7	40.9	43.9	46.9	49.7	52.5	55.2	57.9
0.50	—	—	38.4	41,7	44.9	47.9	50.9	53.7	56.5	59.2	61.9
0.60	—	—	—	—	48.9	51.9	54.9	57.7	60.5	63.2	65.9
0.70	—	—	—	—	—	55.9	58.9	61.7	64.5	67.2	69.9
0.80	—	—	—	—	—	59.9	62.9	65.7	68.5	71.2	73.9
0.90	—	—	—	—	—	—	66.9	69.7	72.5	75.2	77.9
1.00	—	—	—	—	—	—	70.9	73.7	76.5	79.2	81.9

Metabolisable energy requirements for milk

Information needed:

EV_l: the energy value of milk

Y: milk yield

K_l: the efficiency of utilisation of Metabolisable Energy for milk production is assumed to be constant at 0.62 (MAFF, 1987).

ME_l: Metabolisable energy for milk, which was calculated to include a 5% safety margin using the equation:

$ME_l = 1.694\ EV_l$ MJ/kg milk

Average values for solid non-fat (SNF) and butter fat (BF) were used to calculate EV_l. The chosen values were 98.7 and 32.5 (g/kg) for SNF and BF respectively (Patel et al., 2016).

$EV_l = 0.0386\ BF + 0.0205\ SNF - 0.236$ (MAFF, 1987)

Ev_l is the energy value of milk secreted in MJ/kg

SNF is the solids-non-fat in g/kg

BF is the butterfat in g/kg

$EV_l = 0.0386 \text{ X } 32.5 + 0.0205 \text{ X } 98.7 - 0.236 = 3.042$

The ME requirements for milk = $1.694\ Ev_l$ (MJ/kg milk)

$MEl = 1.694\ (0.0386 \text{ X } 32.5 + 0.0205 \text{ X } 98.7 - 0.236) = 5.153$ MJ/Kg

Thus a 550 kg camel producing 10 kg milk (3.5% BF) would require about 92 MJ of ME per day.

It is advisable to use your own set of data on chemical composition of milk in order to generate estimates of EV_1 and ME requirements for milk production that are more relevant to your production conditions. For instance, milk containing 25.8 and 80.8 g/kg of fat and SNF, respectively (Nagy et al., 2017), would have an energy value of 2.42 MJ/kg and an ME requirement of 4.09 MJ/kg. Estimates of ME requirements for camel milk yield with different fat and SNF contents are presented in Table 3 & Figure 5.

Protein requirements for camel

Camels meet their amino acid requirements for maintenance and production from the microbial protein synthesised in the compartmental stomach and the digestible fraction of the dietary protein that escapes foregut fermentation. While camels require amino acids, their foregut microbiota require much simpler nitrogenous compounds such as ammonia for the synthesis of amino acids and the build-up of their cell proteins. The can also use free amino acids and short peptides.

Table 3. Metabolisable energy requirements for camel milk with different fat and SNF contents

Fat%	SNF%	EV_l (MJ)	MJ of ME per kg Milk
2.5	10.295	2.840	4.810
3	10.013	2.975	5.040
3.5	9.731	3.110	5.270
4	9.449	3.245	5.500
4.5	9.168	3.380	5.720
5	8.886	3.516	5.950

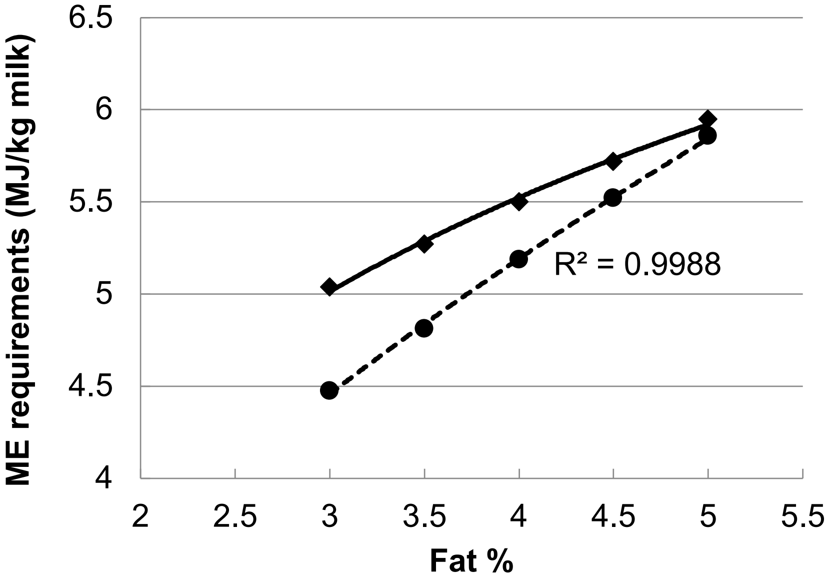

Figure 5. Metabolisable energy allowances for milk yield (MJ/kg milk) of camels, relationship with butterfat contents of milk (2 to 5.5%). Data calculated using the equations adopted by MAFF (1987) and efficiency of utilisation of ME for milk from Guerouali and Wardeh (1998), **dotted line** for cow's milk and **solid line** for camel's milk.

Ruminants are relatively inefficient utilisers of feed nitrogen (Hristov et al., 2018). Feed nitrogen conversion to milk nitrogen is only 27% efficient and only 14% is converted to body gain (Hristov et al., 2018). Similarly, camels waste large proportions of ingested feed nitrogen and only 14.9% of the intake and 23.5% of that digested is retained in the camel's body (Farid et al., 1995). In his work, Farid (1995) used factorial procedures to established protein requirements. The amounts of digestible crude protein (DCP) required for maintenance was 2.181 g per kg $BW^{0.75}$ and the allowance was 2.290 g per $kg^{0.75}$ after adding a 5% safety margin. Accordingly, DCP requirements for maintenance are shown in Table 4 and illustrated in Figure 6.

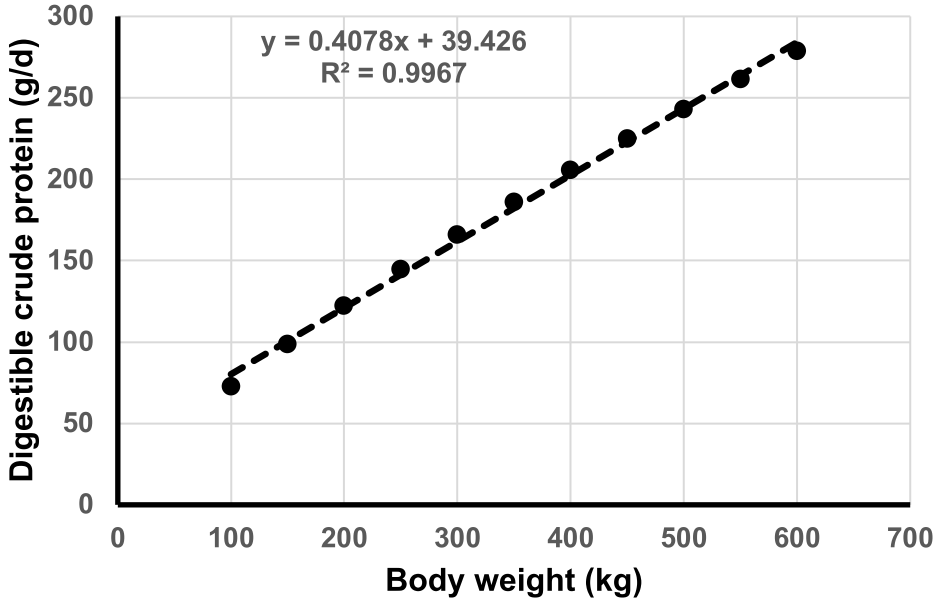

Figure 6. Digestible crude protein (DCP) requirements for maintenance of camels. Adapted from Farid (1995).

Table 4. Digestible crude protein (DCP) and total crude protein (TCP) maintenance requirements for camels (g/day).

Body weight (kg)	DCP (g/day)	TCP (g/day) *
100	72.7	120.3
150	98.7	163.3
200	122.4	202.5
250	144.7	239.4
300	165.8	274.4
350	186.1	307.9
400	205.6	340.2
450	224.7	371.8
500	243.1	402.2
550	261.3	432.3
600	278.8	461.2

*Total crude protein estimates were calculated using a total tract apparent digestibility coefficient value of 63.46% (Farid, 1995) and with added 5% as a safety margin.

There is no information on the efficiency of conversion of dietary nitrogen (dietary N) to milk nitrogen (MN) or gain nitrogen (GN). However, estimates on cattle could be used at this stage, which could be later be experimentally verified and corrected for camels. Efficiency of conversion of dietary N into MN and GN was estimated to be 27 and 14%, respectively (Hristov et al., 2011). Using the 27% constant for MN to calculate crude protein requirements for milk production (g CP/kg milk), protein content of milk was estimated in two conclusive studies and found to range between 26.0 and 29.5 g/kg milk (Nagy et al., 2012; Nagy et al., 2017). The highest value was considered in this paper for the calculation of protein requirements for milk as it represented a large number of lactating camels (n = 1,528) over a period of 5 years. The protein content value of 29.5 g/kg milk corresponds to 4.624 g N/kg milk, based on a conversion factor of 6.38 for milk protein. Accordingly, for a 4.624g N/kg of milk using the efficiency of conversion of dietary N to MN, each kg of milk would require 17.13 g dietary N, which is equivalent to 107 g of dietary crude protein.

Concluding remarks

Energy and protein requirements for the Arabian camel (*Camelus dromedarius*) have been calculated using respiratory estimates of basal metabolism and nitrogen and energy balance data. Calculated values indicate that metabolisable energy requirements for maintenance of camels are lower than those of cattle, while requirements for milk yield is higher. Protein requirements have also been also calculated for both maintenance and milk yield. These values can be used as a guideline by nutritionists when designing diets for their camels. However, further testing is required under different field conditions to assess and verify the suitability of these estimates.

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