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Abstract
Apparent digestibility coefficients of unprocessed animal carcass diets were determined with captive cheetahs (*Acinonyx jubatus*) in the Bloemfontein Zoological Gardens. Procedures were developed to conduct digestibility trials with a sub-adult male and a female cheetah, each comprising three replications in succession with the sub-adult male and a single trial with the female. The diets comprised the unprocessed hind limbs or carcass portions of donkeys (*Equus asinus*) or horses (*E. caballus*). A carcass portion or 'trial diet', namely one of the two symmetrical hind limbs of a donkey or horse, was fed to a specific leopard and the other hind limb, the 'mirror image carcass portion' was retained and frozen pending analysis. Faeces excreted and food refused were collected, processed, frozen and stored pending analysis. Mean dry matter (DM) intake was 1.409 kg and 1.826 kg respectively for the male and female cheetah, with mean apparent DM digestibility coefficients of 0.929 and 0.952. The apparent digestibility coefficients for crude protein (CP), lipids and gross energy (GE) were 0.955 and 0.970; 0.985 and 0.995; 0.932 and 0.967, respectively for the two cheetahs. The apparent digestibility coefficients for minerals were relatively lower, respectively 0.853 and 0.808 for the male and female cheetahs. Apparent digestibility coefficients for food, expressed as DM, can be useful to estimate the food and nutrient intake of large African predators. Evaluating the nutritional status of free-ranging large African predators might be possible in a non-invasive manner.

Key words: *Acinonyx jubatus*, digestibility, non-invasive techniques

Introduction

According to De Waal *et al.* (2005) there is a paucity of information on quantitative nutritional aspects of large African predators such as lions (*Panthera leo*), leopards (*P. pardus*) and cheetahs (*Acinonyx jubatus*), and in general the digestion of diets. Except a few reports (Morris *et al*., 1974; Barbiers *et al*., 1982), little is available on the digestion of diets and absorption of nutrients by large African predators for conditions that closely resemble free-ranging feeding scenarios.

Cheetahs are the most specialised of the 37 cat species (Marker *et al*., 1996). It is the fastest land mammal, reaching speeds up to 110 km/h and unlike other big cats, it is built for speed and agility rather than power (Marker *et al*., 1996). Superficially cheetahs have a more dog-like appearance, but it is a true cat closely related to the lynx, lion, and tiger (Bothma & Walker, 1999). Adult cheetahs weigh on average between 40 and 60 kg (Skinner & Smithers, 1990). The cheetah is now on the list of endangered species. Namibia has the largest number of free-ranging cheetah (Marker *et al*., 1996).

Cheetahs hunt mostly during the with the highest activity during the early morning and late afternoon (Kruuk & Turner, 1967; Schaller, 1972a; Eaton, 1974; Skinner & Chimimba, 2005).

[1] Deceased 9 October 2011.

Presumably cheetahs rely greatly on their eyesight for hunting. According to Bothma & Walker (1999) cheetahs require about 3-4 kg of meat per day to remain in good condition. Its prey is mostly small and medium sized animals of less than 60 kg (Skinner & Chimimba, 2005).

According to Bothma & Walker (1999) the prey species also differ according to the area and the availability of a particular species. In the Serengeti, Tanzania, Thomson's gazelle (*Gazella thomsoni*) accounts for 91% of cheetah kills. In the Kruger National Park, South Africa, impala (*Aepyceros melampus*) comprises 68% of all cheetah kills.

Springbok (*Antidorcas marsupialis*) are hunted with a success rate of 58.5%, while the larger and much more dangerous oryx (*Oryx gazella*) is hunted with a success rate of 14.3% (Bothma & Walker, 1999). In Namibia, kudu calves (*Tragelaphus strepsiceros*), springbok (*Antidorcas marsupialis*), warthog piglets (*Phacochoerus aethiopicus*) and steenbok (*Raphicerus campestris*) are the main prey species of cheetah (Marker *et al.*, 1996).

The success rate of cheetah hunts, like that of the other predators, vary according to several factors, e.g. prey availability, cover provided by vegetation as well as age and size of the prey. In the Nairobi National Park, Kenya cheetahs kill their prey species with a success rate of 37%. However, juvenile prey is hunted at a greater success rate of 76%. The hunting success of a female with cubs is about 41% (Bothma & Walker, 1999). Cheetahs, like other predators, appear to take the younger and more vulnerable animals in a group (Mills, 1984).

Cheetahs eat quickly to avoid losing the kill to other predators and can consume up to 14 kg of food in one sitting (Schaller, 1972b; Marker *et al.*, 1996; Bothma & Walker, 1999). When eating, cheetahs usually start at the buttocks and ribs; the heart and liver are regularly eaten while the intestines are pulled out and generally not eaten (Bothma & Walker, 1999; Skinner & Chimimba, 2005). The blood accumulating in the body cavity is lapped up as an additional source of nutrients and water. The larger bones and skin are usually not eaten. Cheetahs over the age of six months will crush and eat the soft bones of young prey animals (Bothma & Walker, 1999). Cheetahs are not scavengers (Schaller, 1972b), but in the Serengeti, Tanzania a case was documented of cheetahs scavenging on a 2-year old blue wildebeest (*Connochaetes taurinus*) that died of an unknown cause (Caro, 1982). However, the carcass was very fresh and no other scavengers such as vultures or hyaenas had visited it prior to the cheetahs.

Free ranging cheetahs do not have a restricted breeding season (Skinner & Chimimba, 2005). The availability of food greatly influences cheetah reproduction. Cubs stay with the female for almost a year (Skinner & Chimimba, 2005). During the first 12 months of cubs the mother cheetah has a high nutrient requirement, because she must take care of her own needs, as well as that of her cubs. Cheetah cubs start eating meat at the age of 5-6 weeks, the weaning process begins at six weeks and they are usually weaned at the age of three months (Eaton, 1974; Skinner & Chimimba, 2005). From the age of 8-12 months cheetah cubs start hunting actively (Skinner & Chimimba, 2005).

In the wild cheetahs have a high mortality rate and especially cubs are dying at an early age. According to Bothma & Walker (1999) up to 72% of cubs born, die before they emerge from the den at the age of six to eight weeks. The main cause of death of cubs is predation by other predators. According to Bothma & Walker (1999) 50% of cubs in the Serengeti, Tanzania are killed by lions, leopard and hyaena (*Crocuta crocuta*) before they are eight months old. In the Kalahari, 50% of cheetah cubs are killed by starvation and predation before they reach the age of six months. Cubs are also prone to starvation in the den when the mother is away stalking migrating antelope herds. Cubs may join other groups of cheetah and steal food from them to survive. In was noted that cheetah females in captivity regurgitate food for their cubs, but this has yet to be observed in the wild (Bothma & Walker, 1999).

The objective of this study was to develop non-invasive techniques to conduct digestibility trials with captive cheetahs when consuming large portions of unprocessed animal carcasses that mimic the feeding processes of free-ranging large carnivores.

Like for lions and leopards, very little information is available on the quantitative nutrition, food intake and digestive capacity of cheetahs. In a study on the essential fatty acid requirements of cheetahs, it was concluded that being obligate carnivores, cheetahs must ingest plenty animal lipid to maintain a healthy fatty acid balance (Davidson *et al.*, 1986).

Materials and methods

The study was conducted in the Bloemfontein Zoological Gardens (Bloemfontein Zoo) with a sub-adult male and an adult female cheetah (Borstlap, 2002). Like the lions and leopards (Borstlap, 2002; De Waal *et al*., 2005; De Waal *et al.*, 2021), the two cheetahs were housed in a spacious facility consisting of two brick and concrete enclosed night chambers (2.35 m x 2.6 m and 5.65 m x 2.6 m), with steel grate trapdoors leading to a large open-air leisure yard. The trapdoors are remotely controlled by a system of pulleys and cables. The leisure yard is 729 m^2 and the ground is mostly covered with Kikuyu grass (*Pennisetum clandestinum*), landscaped with a few large rocks and tree trunks, and a shallow water pond.

Two digestibility trials (Trial 1 and Trial 2), comprising three replications (Replications 1, 2 and 3) in succession with the sub-adult male cheetah and a single replication (Replications 1) with the adult female cheetah, were performed as detailed in Table 1.

Like the lions and leopards (Borstlap, 2002; De Waal *et al*., 2005; De Waal *et al*., 2021), the male cheetah was weighed in a non-invasive manner. The female cheetah was involved in a breeding exchange programme and moved from the Bloemfontein Zoo before she could be weighed. A steel grid was placed on top of the two metal beams containing the pressure cells of an electronic cattle scale and positioned in the leisure yard, in front of the trapdoor leading to the night chambers. When the steel grid was placed in the leisure yard, the male cheetah was uneasy and wary towards the foreign object; therefore, he was allowed a few days to get used to its presence before being weighed. After zeroing the scale, the cheetah was lured with food onto the steel grid and the weight recorded. Every effort was made to avoid unnecessary disturbances and stress and he was not weighed while a digestibility trial was underway. The cheetah was weighed before being fed to reduce fluctuations in body weight due to gut fill.

Table 1. The schedule of digestibility trials conducted with the captive male and female cheetahs, being fed large portions of unprocessed donkey or horse carcasses.

Trial	Predator	Carcass type	Replication	Date
1	Male cheetah	Horse	1	24 July 2002
		Horse	2	26 July 2002
		Horse	3	7 August 2002
2	Female cheetah	Donkey	1	1 May 2002
			2	NA*
			3	NA

* NA – not available because the female was relocated due to a zoo breeding exchange programme

In the Bloemfontein Zoo the cheetahs were accustomed to being fed large portions of food routinely three times a week (Sundays, Wednesdays, and Fridays between 14h00 and 15h00), mimicking the feeding habits of free-ranging cheetahs (Borstlap, 2002). The digestibility trials with cheetahs followed this routine with a minimum change in the feeding routines.

Borstlap (2002) developed specific procedures to feed large sections of unprocessed animal carcasses to large African predators such as lions, leopards and cheetahs and, very important, being able to obtain homogenous representative samples from the same carcass for analysis

(Figure 1). Borstlap (2002) provided a detailed, step-by-step protocol or guide to conduct intake and digestibility trials with large predators in captivity.

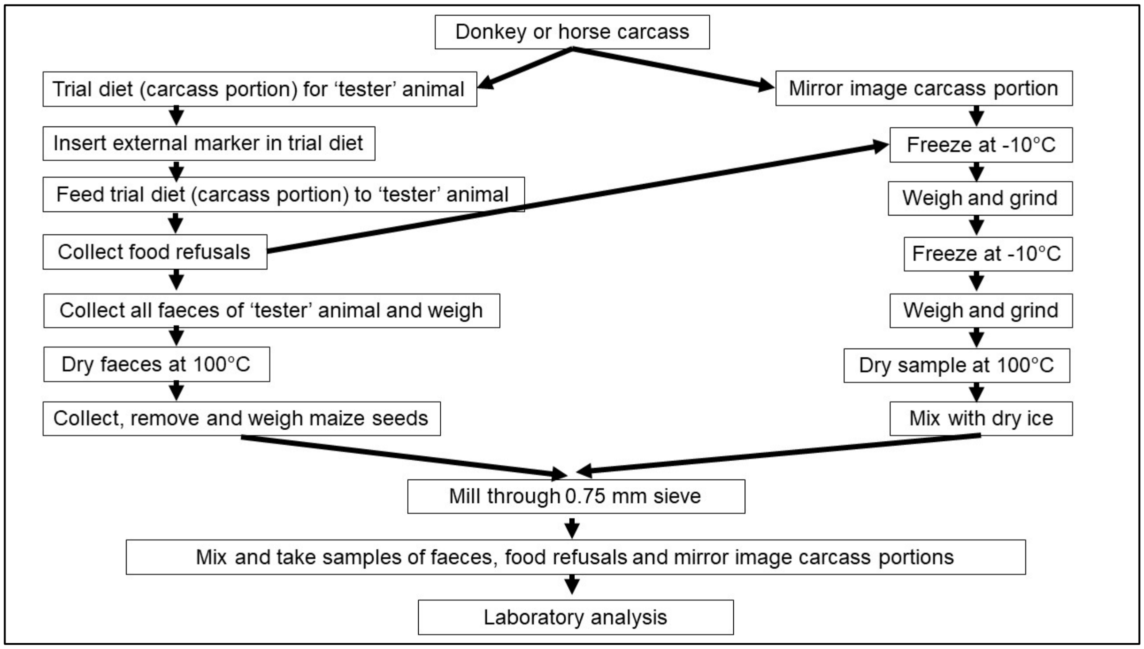

Figure 1 A schematic presentation of the experimental procedures followed in determining the food intake and digestibility trials with large African predators (Borstlap, 2002).

The diets consisted of two symmetrical portions of donkey or horse carcasses that were divided into paired sections, *e.g.* the two hind limbs of a carcass (Borstlap, 2002). Cheetahs, like lions and leopards, have a destructive feeding habit; therefore, one limb section was fed to a specific cheetah ('trial diet') and the other symmetrical limb section ('mirror image carcass portion') was retained for analysis. It was assumed the mirror image carcass portion retained in each trial was identical in nutrient composition to the corresponding symmetrical trial diet offered to a cheetah.

The donkeys (*Equus asinus*) or horses (*E. caballus*) were humanely harvested with a silenced rifle on a nearby farm and transported to the Bloemfontein Zoo. After eviscerating, but not skinning the donkey or horse carcasses, the hind limbs were severed by cutting between the last lumbar and first sacral vertebrae before the pelvis. A butcher's meat saw was used to cut through the length of the sacral vertebrae to separate the two hindquarters, thus yielding two mirror images of a hindquarter each. The lower part or the hind leg was removed by cutting through the heel joint just below the tibia above the tarsus. The trial diet and corresponding mirror image carcass portion were weighed on a large platform scale. The mirror image carcass portions were sealed in large plastic bags, frozen and stored at -10°C pending further processing and analysis.

The two cheetahs shared facilities in the Bloemfontein Zoo; therefore, like with the two lions and the two leopards, an additional method of identification was used with an external marker to lace or mark the faeces of one individual (Borstlap, 2002). Thirty yellow maize (*Zea mays*) seeds were inserted into each trial diet before being offered to a cheetah ('tester' cheetah). Furthermore, the cheetah ('filler' cheetah) that was not participating in that specific intake and digestibility trial was fed either chicken tripe or part of a skinned donkey ribcage. The dual system of identification made it easy to distinguish between the faeces of the two cheetahs.

The procedures have been described in detail (Borstlap; 2002; De Waal *et al*., 2005; De Waal *et al*., 2021), but in the interest of completeness it is detailed again. Before feeding in a trial commenced between 14h00 and 15h00, the two cheetahs were lured into separate night chambers and closed behind trapdoors. The leisure yard was inspected and all faeces, food refusals and bone remaining from previous meals removed.

The ‘filler’ cheetah’s food (skinned donkey or horse ribcage or chicken tripe) was placed in the leisure yard, the service gate closed remotely and locked. The trial diet, marked in advance with 30 maize seeds, was then placed in a vacant night chamber and after closing and locking the gate, the ‘tester’ cheetah was allowed to start feeding on the trial diet and the time recorded. The ‘filler’ cheetah was then released back into the leisure yard to start feeding on its meal. The ‘tester’ cheetah stayed overnight in its night chamber to allow it to consume as much of the trial diet as possible and to prevent the ‘filler' cheetah from also feeding on the trial diet. This prolonged separation of the cheetah while feeding was the only deviation in the trial routine from the usual feeding routine practiced in the Bloemfontein Zoo.

The next morning, remains of the trial diet not consumed (food refusals) was collected, sealed in plastic bags, weighed, frozen and stored at -10°C pending further processing.

All faeces excreted by the ‘tester’ cheetah were collected from early in the morning the day after the trial diet was consumed. The time of faecal collection was recorded. Inspections for freshly voided faeces were made at 3-hour intervals during daylight only to minimise disturbance of the cheetahs. The faeces were picked up with a large metal spatula, sealed in airtight plastic bags, weighed, frozen and stored at -10°C. Visible contamination of faeces with grass, twigs and soil were removed before weighing. Only faeces of the ‘tester’ cheetah originating from the trial diet were collected. Faeces originating from a specific trial diet were usually excreted within 48 to 72 hours from offering the meal.

The frozen mirror image carcass portions and food refusals from the trial diets were taken from cold storage, cut into smaller pieces with a butcher’s meat saw (to fit in the holding chamber of an animal carcass grinder) and then kept frozen again (Borstlap, 2002). The smaller frozen carcass pieces were removed one by one from the freezer and ground through a heavy duty, animal carcass grinder. The 64 circular grinder blades produced considerable heat (friction) during the process of grinding the frozen carcass pieces, comprising flesh, bone, skin, and hair and a substantial amount of water was lost in the form of visible water vapour or steam. This water loss was estimated by difference in weight to correct the dry matter (DM) content of the sample.

After thoroughly mixing the ground animal material (mirror image carcass portions and food refusals), representative samples were taken, weighed in duplicate on pre-weighed stainless steel pans and dried at 100°C for 16 hours in a force draught oven to determine the DM content.

Representative samples of the ground carcass material and food refusals were mixed in a ratio of 1:1 (v:v) with crushed dry ice (frozen CO_2) and ground through a 0.75 mm sieve in a conventional Wiley mill. The dry ice kept the samples very cold and prevented the fat from smearing too much during the grinding process. The ground samples were stored in plastic containers with screw-on lids at -10°C pending analysis.

The faeces collected during a trial were dried separately on stainless steel pans at 100°C for 16 hours in a force draught oven and the DM content determined. The maize seeds were removed and weighed, and the weight subtracted from the dry mass of the faeces. The dried faeces were ground through a 0.75 mm screen in a conventional Wiley mill, mixed and representative samples stored in plastic containers with screw-on lids pending analysis.

The crude protein (CP) content of samples was determined on a DM basis with a Leco® nitrogen (N) analyser (Leco® Corporation, 2001). A factor of 6.25 was used to convert the N content of samples to CP content (McDonald *et al*., 2011). The lipid content of samples was determined in a Soxhlet apparatus, using the hexane method (AOAC, 2000). The mineral (ash) content of samples was determined on a DM basis by incinerating samples in duplicate in porcelain crucibles for 4 hours at 600ºC in a muffle furnace (AOAC, 2000). The gross energy (GE) of samples was determined on a DM basis with an adiabatic bomb calorimeter (dds CP400 calorimeter by digital data systems c.c.) (AOAC, 2000).

In each trial, the nutrient composition of the food and the nutrient intake of the 'tester' cheetah were determined by subtracting the total quantity (expressed in kg) DM, CP, lipids, minerals and GE in the refusals from that contained in the mirror image carcass portions.

The apparent digestibility of food, or nutrients, is best defined as the proportion of ingested food, or nutrients, not excreted in the faeces and, therefore, assumed to be absorbed by the animal (McDonald *et al*., 2011) and calculated as follow:

$$\text{Apparent digestibility coefficient} = \frac{(\text{Food or nutrient intake}) - (\text{Food or nutrient excreted in faeces})}{\text{Food or nutrient intake}}$$

Where intake (kg) = (kg food or nutrient presented) – (kg food or nutrient refused)

The descriptive statistics were generated using Proc Means (SAS, 1991).

Results

It is difficult and dangerous to weigh large predators without the individuals being properly restrained or chemically immobilised. Therefore, in this study only the sub adult male cheetah was weighed once with the non-invasive procedure described previously; the cheetah weighed 40.5 kg. As stated previously, the female cheetah was part of a breeding exchange programme and moved from the Bloemfontein Zoo before she could be weighed.

Enough stock of donkeys was not available at a certain stage of the study; therefore, two horses were sourced by the ALPRU research team to conduct the three replications with the male cheetah (Borstlap, 2002).

The composition of the donkey or horse carcass portions fed to the two cheetahs during the two intake and digestibility trials, comprising three replications for the male and a single replication for the female, is shown in Table 2.

Table 2. Nutrient composition and energy content of the donkey or horse carcass portions[1] fed to the two captive cheetahs (*A. jubatus*) during the two trial periods.

Trial	Cheetah	Replication	Dry matter (DM) g/kg	Crude protein (CP) g/kg DM	Lipids g/kg DM	Minerals g/kg DM	Gross energy (GE) MJ/kg DM
1	male	1[2]	260.9	764.6	110.3	106.9	23.837
		2[2]	270.5	771.1	117.6	115.0	22.748
		3[2]	246.9	888.9	62.4	63.3	22.695
2	female	1[3]	324.8	632.7	320.1	82.4	27.659

[1] Based on the analysis of the four symmetrical 'mirror image carcass portions' that were retained while the corresponding four carcass portions ('trial diets') were fed to the cheetahs.
[2] Horse carcasses portions.
[3] Donkey carcasses portions.

The feed intake, faeces excreted and apparent digestibility coefficients for the male and the female cheetahs fed diets of unprocessed donkey or horse carcass portions, expressed on a fresh and a DM basis respectively, are presented in Table 3 and Table 4.

Table 3. Fresh food intake, the faeces excreted and apparent digestibility coefficients of diets consisting of donkey or horse carcass portions (expressed on a fresh, or as fed, basis) by a male and a female cheetah.

Trial 1				Trial 2			
Male cheetah				Female cheetah			
Replication	Fresh food intake kg	Fresh faeces excreted kg	Digestibility coefficient	Replication	Fresh food intake kg	Fresh faeces excreted kg	Digestibility coefficient
1[1]	5.110	0.241	0.953	1[2]	5.621	0.309	0.957
2[1]	5.056	0.360	0.929	NA[3]			
3[1]	6.184	0.327	0.947	NA[3]			
Mean	5.450	0.309	0.943	NA[3]			
SD	0.636	0.061	0.013	NA[3]			
CV	11.674	19.805	1.326	NA[3]			

[1] Horse carcass portions.
[2] Donkey carcass portions.
[3] Not available due to zoo exchange breeding program.

Table 4. Dry matter (DM) intake, faeces excreted and apparent DM digestibility coefficients of diets consisting of donkey or horse carcass portions by a male and a female cheetah.

Trial 1				Trial 2			
Male cheetah				Female cheetah			
Replication	Dry matter (DM) intake kg	Dry matter (DM) excreted kg	Digestibility coefficient	Replication	Dry matter (DM) intake kg	Dry matter (DM) excreted kg	Digestibility coefficient
1[1]	1.333	0.090	0.933	1[2]	1.826	0.088	0.952
2[1]	1.368	0.118	0.914	NA[3]			
3[1]	1.527	0.093	0.939	NA[3]			
Mean	1.409	0.100	0.929	NA[3]			
SD	0.103	0.015	0.013	NA[3]			
CV	7.338	15.496	1.427	NA[3]			

[1] Horse carcass portions.
[2] Donkey carcass portions.
[3] Not available due to zoo exchange breeding program.

The nutrient composition and energy content of the food ingested by the male and the female cheetahs fed diets of unprocessed donkey or horse carcass portions, are presented in Table 5.

Table 5. The nutrient composition and energy content of the food ingested from diets consisting of donkey or horse carcass portions by a male and a female cheetah.

Trial	Cheetah	Replication	Dry matter (DM) g/kg	Crude protein (CP) g/kg DM	Lipids g/kg DM	Minerals g/kg DM	Gross energy (GE) MJ/kg DM
1	Male	1[1]	260.901	764.572	110.287	106.948	23.837
		2[1]	270.503	771.128	117.604	114.993	22.748
		3[1]	246.935	888.853	62.382	63.300	22.695
2	Female	1[2]	324.805	632.676	320.118	82.407	27.659
		Mean	275.786	764.307	152.598	91.912	24.235
		SD	34.082	104.968	114.334	23.578	2.343
		CV	12.358	13.698	74.925	25.653	9.667

[1] Horse carcass portions.
[2] Donkey carcass portions.

The CP, lipid, mineral and energy intake, faeces excreted and apparent digestibility coefficients for CP, lipids, mineral and energy by the male and the female cheetahs fed diets of unprocessed donkey or horse carcass portions, are presented in Tables 6 to 9.

Table 6. The crude protein (CP) intake, faeces excreted and the apparent CP digestibility of diets consisting of donkey or horse carcass portions by a male and a female cheetah.

Trial 1				Trial 2			
Male cheetah				Female cheetah			
Replication	Crude protein (CP) intake kg	Crude protein (CP) excreted kg	Digestibility coefficient	Replication	Crude protein (CP) intake kg	Crude protein (CP) excreted kg	Digestibility coefficient
1[1]	1.019	0.047	0.954	1[2]	1.155	0.034	0.970
2[1]	1.055	0.075	0.929	NA[3]			
3[1]	1.357	0.043	0.968	NA[3]			
Mean	1.144	0.055	0.950	NA[3]			
SD	0.186	0.018	0.020	NA[3]			
CV	16.243	32.308	2.130	NA[3]			

[1] Horse carcass portions.
[2] Donkey carcass portions.
[3] Not available due to zoo exchange breeding program.

The nutrient composition and energy content of the faeces collected from the male and the female cheetahs fed diets comprising large portions of unprocessed donkey or horse carcass portions, are presented in Table 10.

The water intake derived from their diets by the male and the female cheetahs fed unprocessed donkey or horse carcass portions, is presented in Table 11.

Table 7. The lipid intake, faeces excreted and the apparent lipid digestibility of diets consisting of donkey or horse carcass portions by a male and a female cheetah.

Trial 1				Trial 2			
Male cheetah				Female cheetah			
Replication	Lipid intake (kg)	Lipid excreted (kg)	Digestibility coefficient	Replication	Lipid intake (kg)	Lipid excreted (kg)	Digestibility coefficient
1[1]	0.147	0.002	0.983	1[2]	0.584	0.003	0.995
2[1]	0.161	0.002	0.989		NA[3]		
3[1]	0.095	0.002	0.984		NA[3]		
Mean	0.134	0.002	0.985		NA[3]		
SD	0.035	0.000	0.003		NA[3]		
CV	25.729	25.518	0.304		NA[3]		

[1] Horse carcass portions.
[2] Donkey carcass portions.
[3] Not available due to zoo exchange breeding program.

Table 8. The mineral intake, faeces excreted and the apparent mineral digestibility of diets consisting of donkey or horse carcass portions by a male and a female cheetah.

Trial 1				Trial 2			
Male cheetah				Female cheetah			
Replication	Mineral intake (kg)	Mineral excreted (kg)	Digestibility coefficient	Replication	Mineral intake (kg)	Mineral excreted (kg)	Digestibility coefficient
1[1]	0.143	0.020	0.861	1[2]	0.150	0.029	0.808
2[1]	0.157	0.016	0.897		NA[3]		
3[1]	0.097	0.019	0.802		NA[3]		
Mean	0.132	0.018	0.853		NA[3]		
SD	0.032	0.002	0.048		NA[3]		
CV	23.922	10.315	5.623		NA[3]		

[1] Horse carcass portions.
[2] Donkey carcass portions.
[3] Not available due to zoo exchange breeding program.

Discussion

The larger bones and skin of prey is usually not eaten by cheetahs when feeding (Bothma & Walker, 1999). During the three trials with the male cheetah, the skin was only once left uneaten and in two of the three trials the entire skin with hair was consumed. In the single trial with the female cheetah the skin and hair were left uneaten. However, on a separate occasion it was observed that the female did consume the entire skin and hair of a carcass portion. However, the large bones were left uneaten by both the male and female cheetahs.

Like with the lions and leopards (Borstlap, 2002; De Waal *et al*., 2005; De Waal *et al*., 2021), the apparent digestibility of fresh food (Table 3) was higher than the apparent digestibility when expressed on a DM basis (Table 4). Furthermore, the low coefficients of variation found in these cases for the apparent digestibility of fresh and DM in food (Tables 3 and 4) suggest that there was a high measure of repeatability in the techniques applied.

Table 9. The gross energy (GE) intake, the GE of the faeces excreted and the apparent GE digestibility coefficient of diets consisting of donkey or horse carcass portions by a male and a female cheetah.

Trial 1				Trial 2			
Male cheetah				Female cheetah			
Replication	Gross energy (GE) intake (MJ)	Gross energy (GE) excreted (MJ)	Digestibility coefficient	Replication	Gross energy (GE) intake (MJ)	Gross energy (GE) excreted (MJ)	Digestibility coefficient
1[1]	31.780	1.720	0.946	1[2]	50.494	1.682	0.967
2[1]	31.111	3.030	0.903	NA[3]			
3[1]	34.657	1.796	0.948	NA[3]			
Mean	32.516	2.182	0.932	NA[3]			
SD	1.884	0.735	0.026	NA[3]			
CV	5.794	33.677	2.752	NA[3]			

[1] Horse carcass portions.
[2] Donkey carcass portions.
[3] Not available due to zoo exchange breeding program.

Like with the lions and leopards, the high apparent CP digestibility by cheetahs (Table 6) was reduced because of the large amount of hair excreted in the faeces. Hair, consisting of keratin, is largely indigestible and passes through the digestive tract of the predator unaffected by the hydrochloric acid secreted in the stomach and digestive enzymes of the carnivore digestive system. Therefore, ingested hair protein does not contribute to the digestible protein fraction of the diet. Another factor contributing to the reduction of CP digestibility is the presence of metabolic faecal nitrogen originating from digestive enzymes, mucus and epithelial cells sloughed off the walls of the intestines by the passing digesta. Some of the predator's own hair is also ingested through the act of grooming. This hair also passes through the digestive tract and excreted in the faeces, further contributing to the CP content in the faecal material.

Table 10. The nutrient composition and energy content of the faeces collected from a male and a female cheetah fed unprocessed horse or donkey carcass portions.

Trial	Cheetah	Replication	DM g/kg	Crude protein g/kg DM	Lipids g/kg DM	Minerals g/kg DM	Gross energy MJ/kg DM
		1	371.970	522.800	27.833	221.323	19.191
1	Male	2	327.716	630.900	15.515	138.070	25.715
		3	282.998	462.100	16.456	207.221	19.413
2	Female	1	366.099	389.400	33.488	329.952	19.179
Mean			337.196	503.550	23.323	224.141	20.875
SD			41.118	106.003	8.790	79.369	3.229
CV			12.194	21.051	37.688	35.410	15.468

On several occasions, small amounts of fresh blood, ostensibly originating from the predators themselves, were detected on the faeces. Sharp or coarse objects injuring the epithelial lining of the large intestine probably caused the bleeding. This phenomenon was observed in the lions, leopards, and cheetahs (Borstlap, 2002). It would undoubtedly also contribute to some of the CP present in the faeces not originating from the ingested food and therefore reducing slightly the apparent CP digestibility coefficients.

Table 11. Water intake derived from the diets consisting of unprocessed donkey or horse carcass portions by a male and a female cheetah.

Cheetah	Water intake derived from the trial diets kg	Water intake as a percentage of body weight %	Water intake per metabolic size kg/kg$W^{0.75}$
Male	4.041	10.0	0.252
Female	3.795		

Like with the lions and leopards (Borstlap, 2002), the consistency of the cheetah scat changed from a soft, fluid-like consistency to a harder, firm and sausage-like form. During the periods of collection after feedings the colour of scat excreted changed from a dark reddish brown, to black, to a dark brown, to a black colour.

Like with the male and female lions and leopards (Borstlap, 2002), the mean apparent lipid digestibility coefficients (Table 7) of the male and female cheetahs were very high.

The mean apparent mineral digestibility coefficients (Table 8) observed for the male (0.853) and female (0.808) cheetahs were relatively higher than those for the male and female lions and leopards.

Meat is a good source of minerals, especially iron (Fe), phosphorus (P), copper (Cu), and manganese (Mg). Muscle is generally low in calcium (Ca), but blood plasma and especially bone have high Ca contents (McDonald *et al*., 2011). The sub-adult male cheetah probably still had a relatively higher mineral requirement for skeletal growth. The female was an adult, but still had an apparent high mineral (ash) digestibility coefficient, although adult animals do not have a high mineral requirement for skeletal growth. Therefore, it was concluded that cheetahs, being very fast running animals and relying on speed to hunt prey, had higher requirements for minerals such as Ca for muscle contraction and P for energy metabolism.

The mean apparent GE digestibility coefficients (Table 9) observed for the male and female cheetahs were in line with those observed for the male and female lions and leopards in this study (Borstlap, 2002; De Waal *et al*., 2005, De Waal *et al*., 2021). The high apparent GE digestibility by large predators such as cheetahs, lions, and leopards, is an indication of the high efficiency of energy utilisation from the carnivorous diets.

The mean faecal CP content of 503.550 g/kg (Table 10) shows the extent to which indigestible hair originating from the carcass portion passes through the digestive system of cheetahs. The low mean faecal lipid content of 23.323 g/kg shows the large extent to which lipids are digested and absorbed in the digestive tract. The faecal mineral content is largely due to the pieces of indigestible bone passing through the digestive tract. The mean faecal GE content of 20.875 MJ/kg shows the extent to which GE is extracted from the diet. It can however be noted that the relatively higher GE content of the cheetah faeces is a result of the relatively lower apparent lipid digestibility by the cheetahs in this study allowing the passage of more lipids into the faeces resulting in a higher GE content.

The data (Table 11) confirmed that cheetahs obtain a considerable amount of water from their diets. Lions, leopards, and cheetahs will drink water regularly when it is available (Eloff, 1973;

1999; Green *et al*., 1984; Bothma & Walker, 1999). However, water may account for 85% of the total mass of the bodies of prey animals (Green *et al*., 1984). Therefore, predators such as lions, leopards and cheetahs may obtain sufficient water from the blood and soft tissue of the prey animals to meet a considerable part of their water requirements.

It is common practice at some zoos and other facilities where carnivores are kept in captivity to supplement diets with bone meal or commercial mineral supplements. In the case of lions, the low digestibility of minerals is reason to believe that the supplementation of especially adult animals is not necessary (Borstlap, 2002). However, leopards and cheetahs have higher apparent digestibility of minerals. It may be concluded, especially for captive cheetahs, that mineral supplementation may by worthwhile to prevent mineral deficiencies because they cannot crush large bones offered in some diets.

The procedures used to yield estimates of the food and digestible nutrient intake of free-ranging predators such as cheetahs. However, it remains a challenge to observe large predators at close quarters to keep note of feeding sessions and subsequent dropping of faeces, especially in some environments. All the faeces voided must be collected to increase the accuracy of estimating food and digestible nutrient intake. Due to the time interval it may take to collect fresh faeces excreted by a specific cheetah without risk and the varying rate at which water evaporates from the faeces until it is collected, it is advised that the DM content of faeces should be used in estimating food intake.

If such information is available and the techniques described above applied judiciously and further refined, the food and nutrient intake of large African predators can be estimated. Thus, nutritional status of cheetahs can be determined in a non-invasive manner during the different physiological stages of their lives.

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