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Dietary management of a hamadryas baboon (*Papio hamadryas*) troop to improve body and coat condition and reduce parasite burden

Francis Cabana*, Praveena Jayarajah, Pei Yee Oh, Chia-Da Hsu

Wildlife Nutrition Centre, Wildlife Reserves Singapore, 80 Mandai Lake Road, Singapore 729826
**For correspondence: Francis Cabana; francis.cabana@wrs.com.sg; +65 6360 8652*

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Abstract

Feeding primates in zoological institutions is no simple task due to their varying nutritional requirements and complex social organisation. Daily feeding in a zoo enclosure of high quality food items, such as fruits, may encourage food-based dominance within a group, which leads to unequal division of energy and nutrients. This can affect their body condition (as a proxy for weight), with dominant animals tending to be over-conditioned and subordinate individuals under-conditioned. This is particularly true with large troop primates, such as hamadryas baboons (*Papio hamadryas*). The hamadryas baboon troop at Wildlife Reserves Singapore (WRS) exhibits food-based aggression and also suffers chronic parasite burdens. We aimed to lower the soluble carbohydrates and increase the fibre content of the diet of this troop to decrease food-based aggression with a view to reducing the large range of body conditions and high parasite burden evident within the WRS troop. We collected 10 mixed-age fresh faecal samples from before and after the diet change and performed a quantitative analysis of worm burden of each sample. We recorded body condition (on a scale of 1 [emaciated] to 5 [obese]) and coat scores (1 [poor quality] to 5 [excellent quality]) for six male baboons and their harems, weekly for four weeks before and four weeks after the diet change. The diet was changed from one mostly comprising fruit, rice and chicken to one comprising vegetables, pulses and browse. The average body condition of the troop was significantly reduced from 4.2 to 3.7 and the coat condition was significantly increased from 2.9 to 3.5. The average parasite count decreased from 1670 to 610; however, this was not significant. A low soluble carbohydrate and high fibre diet was conducive to healthier body conditions and coat conditions of a *P. hamadryas* troop, and may also have helped reduce the parasite burden.

Introduction

Providing adequate primate diets in zoological institutions is no straightforward task, due not only to their complex and varying nutritional requirements, but also because of their incredibly complex social organisations (de Waal 1989). The distribution of food resources are important factors in determining the size and social structure of a primate species (van Schaik and van Hoof 1983). Clumped food is conducive to a more competitive situation than dispersed food in wild primates (van Schaik 1989). Captive primates, however, may not react as expected when compared with their wild counterparts. This may be a result of the combined influence of population density, proximity to undesired or allied individuals, homogeneity of the captive environment or exposure to a different climate (Angst 1980; de Waal 1989; Rowell 1967).

The quality of food may also be an important factor in influencing social structures of primates (van Schaik and van Hoof 1983). The nutritional quality of food given to zoo animals is generally superior to most food items eaten by wild primates (Schwitzer and Kaumanns 2001; Plowman 2013). Commercially-available fruits and vegetables consumed by humans, in general, have been cultivated for a higher soluble carbohydrate content and weight (and thus energy), and a lower fibre content. This may skew the inherent value assigned to these food resources by captive primates and may lead to increased dominance, food hoarding, aggression and possibly abnormal behavior patterns (Britt et al. 2015). Traditional primate zoo diets are often high in fruit and consequently exhibit a high proportion of simple sugars, which can lead to negative health conditions, such as dental disease (Cabana and Nekaris 2015), wasting (Barnard et al. 1988), gut microbiome dysbiosis (Clayton et al. 2016), obesity (Zinner 1999; Schwitzer and Kaumanns 2001), diabetes (Pound et al. 2014) and increased parasite load (Petkevičius et al. 2001). The possible negative effects of typical zoo primate diets may be further exaggerated if primate social systems are based on dominance (Kummer 1968).

Hamadryas baboons (*Papio hamadryas hamadryas*) are social primates that live in groups, dominated and controlled through aggressive dominance (Kummer 1968; Sigg 1980; Abegglen 1984). Males support a harem of females controlled via aggressive herding (Kummer 1968). Their societies are multi-tiered as many harems (traditionally called 'one-man units'; OMUs) form a clan, a few clans form a band and many bands comprise a troop (Schreier and Swedell 2009). This level of social complexity is difficult to recreate in a captive setting (Ryan and Hauber 2016); however, Wildlife Reserves Singapore (WRS) holds a group of 103 *P. hamadryas* which have divided into at least two clans (personal observations). Baboons engage in anti-dominance dispersion by allowing feeding to take place first by dominant OMUs of the dominant clan, followed by next less dominant OMUs and so on and so forth, until the subordinate clan has their turn (Zinner 1999). The most dominant individuals have access to the most highly-prized food items—usually the most energetically dense—while more subordinate individuals must rely on a lower quality diet (Altmann 1998; Zinner 1999). Dominant individuals may ingest more preferred foods than required for their energy maintenance, simply to maintain their dominant stature. We believe this has led to a disproportionate number of over-conditioned, or obese, dominant individuals and under-conditioned, or thin, subordinate individuals. This may also affect the parasite load of the troop, either because of the diminished immune status of stressed, under-conditioned individuals, the high sugar diet of dominant individuals, or a combination thereof.

In the wild, *P. hamadryas* display varied diets depending on their location but seem to rely on Acacia species (*A. senegal, A. nubica, A. tortilis* and *A. clavigera;* Mimosoideae) throughout their range (Nagel 1973; Al-Safadi 1994). They may be restricted by the low food availability within their habitats, as well as presumed low food quality (Swedell 2002; Johnson et al. 2013). They ingest the flowers, seeds and fresh shoots from *Acacia* spp. as well as some other desert plants and grass seeds (Schreier 2010). Doum palm (*Hyphaene thebaica*) nuts are the preferred foods of individuals with access to them (Swedell 2002; Swedell et al. 2008). If the chemical composition of Doum palm nuts are any indication of *P. hamadryas* diet, we would expect a natural diet high in dietary fibre and relatively low in protein and soluble carbohydrates, such as sugars and starches (Nwosu et al. 2008; Aboshora et al. 2014). The nutrient concentrations of foods eaten by wild chacma baboons (*P. hamadryas ursinus*) support this notion, with 10 food items out of 17 having NDF values above 35% dry matter (Johnson et al. 2013). Protein (calculated as available protein; AP) and total non-structural carbohydrates (TNC) were also relatively low, with 13 out of 17 food items having AP values below 15% DM and 11 of 17 having TNC below 30% DM (Johnson et al. 2013). Conversely, cultivated produce used to feed domesticated and captive animals are generally low in fibre and high in soluble carbohydrates, both of which may have important health implications, for example, regarding parasite prevention (Villalba et al. 2016) and weight management (Schwitzer and Kaumanns 2001). The diets of wild *P. hamadryas* thus appear to be of lower nutritional quality than captive individuals of the same species. We aimed to assess the body condition and parasite burden of a population of captive *P. hamadryas* and explore if nutritional management can positively affect these factors. Nutritional management, in this case, involved a diet change to mimic more natural feeding conditions, namely decreasing soluble carbohydrates while increasing fibre and plant secondary metabolites.

Materials and methods

Faecal sampling and analysis

Ten fresh faecal samples were randomly collected from the enclosure's off-exhibit concrete floor with a spatula and placed into faecal collection vessels. The spatula was disinfected between each collection. One month after a complete diet change, another 10 fresh samples were collected for comparison. A modified version of the Wisconsin and Cornell-McMaster methodology (Egwang and Slocombe 1980; Vadlejch et al. 2011) was used to quantify *Trichuris* egg burden. Using a digital weighing scale (A&D, Ek-200i), we weighed out 4 g of faeces from each of the 10 samples. Thereafter, we transferred the weighed portions to a mortar. We added 60ml of Fecasol®, Sodium Nitrate solution, was gradually added into the mortar while the contents were being pounded with a pestle. The contents were thoroughly mixed and a strainer was used to remove faecal matter while the filtrate was collected in a plastic container. A Pasteur pipette was used to aspirate the filtrate and fill both compartments of the McMaster chambers. The filled chambers were left to stand for 5 min before being observed under a light microscope (Nikon e100) at 10× magnification and ova that lay within the columns of each compartment being counted. Equation 1 (EQ 1) was used to determine the number of eggs per gram of faeces. This procedure was repeated one month after the diet was fully accepted by the troop.

EQ 1: Number of eggs/g of faeces = Number of eggs counted × 50

Body condition scoring (BCS) and coat scoring (CS)

The hamadryas baboon troop at WRS consists of 103 individuals representing a range of ages. Six OMU's with recognisable males were selected as representatives for the troop since it was impossible to collect body condition scoring (BCS) data on all individuals. The validated BCS system of Summers et al. (2012) was used as a model for the baboons, comprising a grading of 1–5, with 1 being emaciated and 5 being obese (see supplementary material, table 1). This system worked well for females; however, for adult males scoring relied on the lower body and abdomen, the body parts not hidden by their thick mane. Coat condition was visually scored, using the method described by Honess et al. (2005), using a scale of 1–5, where 1 equated to poor quality and 5 to excellent quality (thick, long and shiny). The baboon BCS and CS were scored weekly by three keepers and one random keeper that changes each week, for a total of four weeks before and four weeks after the diet change. Scores of the six recognisable males and their females and sub adults were collected, but not of juveniles or infants. Female numbers varied weekly within the OMUs as males stole females from other harems; therefore, our total study population varied weekly.

Diet modification

The troop's original diet (Diet 1) consisted of fruits, bread, rice, chicken, eggs, vegetables, browse, forages and pellets while the revised diet (Diet 2) consisted of less fruit (used only during token feedings) and higher proportions of vegetables and browse (Table 1). The pellets fed in both diets were the same, and, according to the manufacturers label, had a composition of 23% crude protein, 5% crude fat and 14% crude fibre or 29% neutral detergent fibre (NDF) (DM basis). The nutrient content of both diets was calculated before the commencement of this study to confirm the expected reduction in soluble carbohydrates and increase in fibre in Diet 2, using nutritional information for each food item previously analysed at the Wildlife Nutrition Centre at WRS. NDF and acid detergent fibre (ADF) were used as representative fibre values within the diets. Total non-structural carbohydrates (TNC)

Table 1: Original and revised diets, in kg of diet as fed, for the study group of 103 hamadryas baboons (*Papio hamadryas*) at Wildlife Reserves Singapore.

Food Category	Original Diet (kg)	Revised Diet (kg)
Fruits	35	3
Leafy veg	0	30
Watery veg	0	17
Root veg	22	25
Bread	2.5	0
Seeds	8	5
Chicken	4.5	0
Rice	30	0
Eggs	40 pcs	0
Napier grass	40	40
Sugar cane	1.2	1.2
Ficus branches	20	20
Primate pellet	2	4
Pulses	0	35
Total	165	180.2

Fruits included apples, bananas, pears and oranges. Leafy vegetables included Chinese cabbage, kang kong and sweet potato leaves; watery vegetables included long beans, French beans, tomatoes and cucumbers; and root vegetables included sweet potato, turnips and beet root. The pulse mix consists of 40% barley, 20% green peas, 20% moong (mung) beans and 20% red lentils. The pellet used was Mazuri Primate Browser Biscuit (Purina Mills Inc., USA).

Table 2: Calculated nutrient contents of the original (Diet 1) and revised diets (Diet 2), on a dry matter basis, for 103 hamadryas baboons (*Papio hamadryas*) at Wildlife Reserves Singapore compared with the nutrient requirements of Old World primates from the National Research Council (NRC, 2003).

Nutrients	Diet 1	Diet 2	Recommendation
Ash (%)	4.05	6.04	
Ca (%)	0.12	0.39	0.55-0.56
Crude fat (%)	12.11	9.81	5
Crude protein (%)	13.18	16.73	8.0-16.7
Fe (mg/kg)	48.88	88.27	100.0-200.0
P (%)	0.26	0.37	0.33-0.44
K (%)	0.51	1.07	
Se (mg/kg)	0.27	0.21	
Na (%)	0.07	0.11	
Vit A (IU A/g)	12.43	27	5.0-14.0
Vit C (mg/kg)	141.02	1296	600
Vit E (mg/kg)	17.19	56.69	56.0-68.0
Zn (mg/kg)	18.85	22	10.0-20.0
ADF (%)	7.89	15.23	10
NDF (%)	14.15	25.35	20
TNC (%)	56.51	42.07	

Abbreviations are calcium (Ca), iron (Fe), phosphorous (P), potassium (K), selenium (Se), sodium (Na), zinc (Zn), acid detergent fibre (ADF), neutral detergent fibre (NDF) and total non-structural carbohydrates (TNC).

were calculated using equation 2 (EQ 2), an approximation for combined sugars and starches. Although this method is crude, it is useful when estimating an overall increase or decrease of soluble carbohydrates by comparison. Conducting an intake study of the target OMUs was not possible due to the baboons' communal living and eating habits. Diet 1 was higher in TNC and protein and lower in fibre compared to Diet 2 (Table 2).

EQ 2: TNC = 100 − ash − crude fat − crude protein − NDF

Statistics

The parasite count data were not normally distributed according to a Shapiro-Wilk test (U=0.813, df=20, P=0.001). A non-parametric Mann-Whitney U test was used to determine if the parasite burdens, BCS and CS data differed between diets. Only data from the first two weeks prior to the diet change, and the last two weeks following diet change, were used for evaluations.

Results

Nutritional content

The average nutrient content of Diet 1 did not meet Old World monkey (OWM) recommendations for calcium, iron, phosphorous, vitamin C, vitamin E, ADF or NDF. Diet 2 met the requirements for phosphorous, vitamin C, vitamin E, ADF and NDF, and provided increased calcium, vitamin C, fat soluble vitamins, iron and protein, as well as decreased TNC content (Table 2).

Body and coat condition

The average body condition score for the troop was 4.2 (SD±1.32) for Diet 1 and 3.7 (SD±0.80) for Diet 2, reflecting a significant change (U=14.37, P=0.014). The average coat condition score for the troop was 2.9 (SD±0.45) for Diet 1 versus 3.5 (SD±0.78) for Diet 2, reflecting a significant change (U=4.83, P=0.001). The 10 baboons with the lowest BCS exhibited an increase of an average

Table 3: Parasite load from randomly sampled hamadryas baboon (*P. hamadryas*) faeces of all ages, both before and after a diet change resulting in lower sugar and higher fibre content.

		1	2	3	4	5	6	7	8	9	10	Average
Trichuris count	Diet 1	4900	3600	0	1200	200	1800	400	2200	1800	600	1670
	Diet 2	2150	0	50	750	650	1050	100	700	0	650	610

of 1.3 and the 10 baboons with the highest BCS exhibited a decrease of an average of 0.9 (Figure 1).

Parasite count

The average *Trichuris* egg count decreased for Diet 2 (Table 3); however, this change was not significant (U=30.00, P=0.130).

Discussion

A decrease in dietary soluble carbohydrates and an increase in proportion of fibre led to a significant difference in body condition and coat quality scores in captive hamadryas baboons. Additionally, average *Trichuris* worm load decreased numerically. The original diet contained highly-prized food items such as chicken and fruits, the provision of which may have led to dominant individuals and OMUs ingesting larger amounts than necessary for weight maintenance. This could have led to excessive energy intake, resulting in over-conditioned dominant individuals. Subordinate individuals and OMUs would have consequently had access to only the less desired food items, usually lower in proportion of soluble carbohydrates and higher in fibre. Diet 2, in contrast, contained no highly-prized foods; dominant individuals may have felt satiated sooner due to the higher fibre content of foods, and may not have overconsumed the less “tasty” available food. Although dominance hierarchies and behaviours undoubtedly still occurred, this could have led to a more even distribution of food resources, thus resulting in weight loss of dominant individuals who were no longer food-motivated to overeat, and weight gain of subordinate individuals who were now able to ingest a larger proportion of the available energy and nutrients.

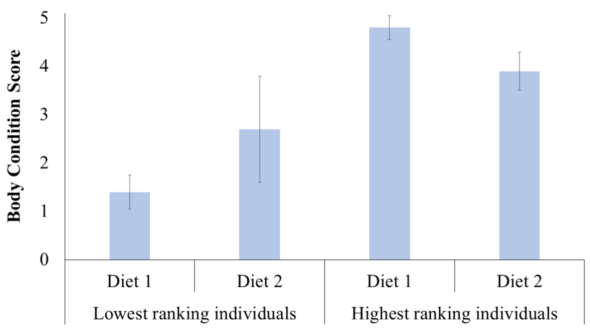

Figure 1. Comparison of the 10 lowest ranking and 10 highest ranking baboon’s body condition scores while being fed Diet 1 and Diet 2, with their error bars being standard deviations.

Coat score significantly increased following the diet change. This improved coat condition may have been due to increased nutrient quality of the diet, a decrease in hair plucking, or a combination thereof. The revised diet contained numerically higher levels of crude protein, iron, zinc, vitamin C, vitamin E and vitamin A, all of which are known to impact hair quality and growth to some extent (Rushton 2002; O’Regan et al. 2008). The improved diet could also have influenced other variables, which were not measured, but which are known to impact skin and hair quality, such as B vitamins and carotenoids (Shim and Dierenfeld 2017). Individual animal dietary intakes varied; however, the odds of ingesting a larger number of critical nutrients of the revised diet compared to the original diet was higher due to the inclusion of more foods higher in these nutrients. Diet 2 also comprised 10% more food (fresh weight basis), which improved the foraging potential for all individuals. Foraging and feeding may have accounted for a significantly larger portion of overall activity budgets during the revised diet, resulting in a reduced likelihood of over-grooming, as reported in guinea pigs (*Cavia porcellus*), rabbits (*Oryctolagus cuniculus*) and macaques (Beynen et al. 1992; Gerold et al. 1997; Beisner and Isbell 2008), but was not recorded in this investigation. If fibre were an important factor contributing to the improved coat condition, it would have occurred through an increased feeding time, and not through nutritional benefits.

Anecdotal reports from the keeper staff at WRS suggest there was less aggression between the baboons, perhaps resulting in less fur being forcefully removed or damaged during a physical altercation. Redirected foraging theory relative to feather/hair condition has also been recorded for chickens (Newberry et al. 2007), domestic pigs (Fraser et al. 1991) and pigtail macaques (*Macaca nemestrina*) (Boccia and Hijazi 1998). Individuals with low coat scores still occurred. For such individuals, the influence of age, stress and/or social rank may have played a more prominent role than activity budget or nutrition per se (Reinhardt et al. 1986; Li et al. 2007; Chancellor and Isbell 2008). Such factors may be teased out over a longer time frame within this group.

The baboon troop was infected with *Trichuris trichiura*, which is a common intestinal parasite of these primates, both in the wild and captivity (Flynn 1973; Munene et al. 1998; Hahn et al. 2003). It is also one of the major intestinal helminthic infections found in humans worldwide (Bundy et al. 1989), mostly affecting children between two and 15 years old and leading to poor physical fitness, growth and appetite (Bundy et al. 1987; Stephenson et al. 1993). High worm burdens were observed in the deceased infant baboons of WRS (less than 1 year old) during both diets, during postmortem examinations. These infants did not yet ingest solid foods, instead relying on their mothers’ milk, and therefore may not have been affected by the diet change, thus biasing our results. Spending a large amount of their time on the ground playing, they may be at constant risk of egg ingestion. This highlights the importance of cleanliness as a tool to decrease parasite load. Nutrition is nonetheless an important factor in the development of intestinal parasites, especially regarding the types of carbohydrates found in the diet (Thomsen et al. 2005). In pigs, a diet high in fibre in the form of inulin and sugar beet pulp significantly decreased the *Trichuris suis* and *Oesophostomum dentatum* burden (Petkevičius et al. 1999; 2001; 2003). Soluble carbohydrate sources, such as rice, which can be rapidly digested in the intestine, were reported to create conditions more favourable for the establishment of parasites (Thomsen et al. 2005). One critical difference between our study and that of Thomsen et al. (2005) (apart from species), was the fibre type(s) used. In the present study, the NDF and ADF content were increased, meaning cellulose and hemi-cellulose both increased, the former of which is only partially digestible in a baboon or a pig. The apparent effect of fibre on parasite burden may have been limited. Sugar beet fibre and inulin were used to increase dietary fibre in growing pigs and did not correlate with controlling *T. suis* burden (Pearce 1999). Instead, Pearce (1999) discussed how having pigs on slated floors decreased the risk of parasite infection compared to pigs on solid floors. This also strongly highlights how important sanitation is to reduce parasite burden. This link has been well established in a variety of animals and should be no different for zoo housed animals (Nansen and Roepstorff 1999; Ziegelbauer et al. 2012).

Conclusion

A diet lower in proportion of soluble carbohydrates and higher in fibre led to a reduction in average body condition scores and an increase in coat quality in the study troop of hamadryas baboons. The diet change failed to cause a significant change in the parasite burden of the troop, although it did decrease the average count. Future studies should separate the faecal samples of adults and infants to verify if infant baboons have a higher parasite burden than adults, regardless of diet. Behavioural observations should also be made to estimate feeding time. Diet is intrinsically related to parasite burden; therefore, this management concept should be explored further in conjunction with different sanitation regimes.

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