Baseline Intake Study for Four Species of Primates in Captivity: Callithrix pygmaea, Nycticebus pygmaeus, Propithecus coquereli and Callithrix geoffroyi

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Abstract

Little information is known in regards to the natural or seasonal diets of primates. In captivity, nutrition can be an important part of preventative medicine and lead to an improved quality of life for primates. To better understand the nutrient intake of four primate species in the collection at the Philadelphia Zoo, we conducted an intake study over a minimum of four days for each species. A spreadsheet was used to track the amounts consumed and convert these numbers to nutrient values. Furthermore, we attempted to correlate known health issues to the nutrients consumed. Finally, we compared diet appropriateness to the gut morphology of each species, where data was available. Our results show an accepted sugar to fiber ratio of 3.29:1, 6.46:1, 10.16:1, and 0.78:1 for the pygmy loris, Geoffroy's marmoset, pygmy marmoset and Coquerel's sifaka, respectively. Our goal was to establish an appropriate, subjective sugar to fiber ratio for each primate. Although there are possible correlations between health issues and consumed nutrients, these were not confirmed and need further evaluation. Overall, this information will be used to better the diets of the primates in the collection at the Philadelphia Zoo.

Introduction

With such a broad range of animals and so much research left to be done, how to best feed each species of primates is not yet fully known (National Research Council, 2003). Because species have different feeding ecologies, the knowledge of one species is not necessarily transferrable to another. For example, New World monkeys, such as tamarins and marmosets, are more prone to Vitamin D_3 deficiencies than Old World Monkeys (National Research Council, 2003). Therefore, we attempted to look at the nutrition of only a few primate species by reviewing the diet intake of four primate species in the collection at the Philadelphia Zoo. We then evaluated what the animals actually ate of the offered diet and the potential the consumed diet may contribute to common issues associated with each species in the Philadelphia Zoo collection. Furthermore, we examined the gut morphology of these animals, where available.

As part of the background information required for this intake study, we reviewed the literature for information regarding the relative gut length or volume of different species of primates, particularly those found in the collection at the Philadelphia Zoo. This information was then compiled and converted to percentages of total gut size to compare the data across species. While there is information available in the literature, it is neither complete nor easily comparable between species. For many species, little to no information exists and where it does, there is little continuity. One problem is that some primates have gut proportions that will change in part due to seasonal fluctuations (Milton, 1999). Another hurdle is that the effects of captivity on the dimensions of the gastrointestinal tract are not known. Many authors, such as Chivers and Hladik (1980), suggest captivity has an impact on gut dimensions; but, as of yet, this is unproven. While some of these sources will use the gut measurements of animals in captivity, others use those of wild animals (Fooden, 1964) further complicating comparisons between species.

Regardless, these relative measurements are important because of the information they can provide regarding the natural and seasonal diets of these animals. A longer or larger small intestine suggests a higher quality diet, whereas a larger or longer colon suggests a lower quality diet (Milton, 1999). A larger stomach, often one that is compartmentalized, reflects a diet of low quality leaves (Fooden, 1964). A longer caecum is often found in folivores, who utilize it for fermentation. Also, exudativores, who feed primarily on gums, have a longer caecum in order to ferment gums (Chivers & Hladik, 1980). These are just general rules and there are many exceptions, but understanding the implication of an animal's gut morphology allows for a better understanding of the natural diet and the potential dietary needs of captive primates.

Furthermore, we explored the relationship between diet and animal issues, that may be associated with diet, in the study species at the Philadelphia Zoo. The four species chosen for the intake study, *Callithrix pygmaea* (pygmy marmoset), *Nycticebus pygmaeus* (pygmy loris), *Propithecus coquereli* (Coquerel's sifaka) and *Callithrix geoffroyi* (Geoffroy's marmoset) all have known issues, potentially associated with diet. These issues include obesity, heart disease, giardiasis, periodontal diseases, and/or microbiome shifts.

The primary objective of this study was to measure the intake of dietary items and then determine the nutrient composition of the consumed portion. We compared the actual nutrient intake to the recommendations of each nutrient as reported by the Nonhuman Primate National Research Council (National Research Council, 2003), our hope being that we may find correlations between nutrient intake and persistent health issues. Next, where the data was available, we would evaluate the consumed diet in relations to gut morphology. Finally, as a subjective goal, we hoped to establish an estimate for an appropriate sugar to fiber ratio for the non-ape primates in the collection at the Philadelphia Zoo.

Materials & Methods

Intake studies were done for four species: Coquerel's sifaka (4 day), pygmy loris (5 day), pygmy marmoset (5 day) and Geoffroy's marmoset (6 day). Study length was dictated by keeper availability and housing limitations. The pygmy loris (female) and pygmy marmoset (male) were singly housed animals. The Coquerel's sifakas were housed as a pair (one male and one female) and the Geoffroy's marmoset group was compromised of four individuals (2.2). The intake studies were done in June and July of 2016. All animals were part of the collection of the Philadelphia Zoo and housed at the Philadelphia Zoo. Intake studies were done in the exhibit enclosures of the animals, except for the Coquerel's sifaka, which was performed in a hospital enclosure while the animals were in quarantine for the female whom was new to the collection.

The first day of the study, the animal keeper (AK) weighed each individual food item (in grams) allocated for the animal(s). Food item weights were recorded in a data collection log and the AK noted any special feeding conditions within the log. The following day, the AK collected orts and placed them in a container for evaluation. The orts were separated into food components and each component was weighed separately (in grams) to determine the amount of each food item consumed by the animal. Consumed amounts were recorded within the same log. A desiccation study was done to evaluate moisture loss of dietary items. The desiccation study was done in the enclosures where the intake study took place. All desiccations were either before or during the intake studies. Small amounts of each food item (about 5 grams) were weighed individually and placed into a metal mesh container. The mesh container allowed free air flow and exposed the enclosed sample food to the same environmental conditions as the animal's diet. The container was secured such that the animal could not open it, and placed in the enclosure with the animal for the length of time the animal typically has access to the offered diet. At the conclusion of the study period each food item was weighed back individually. The purpose of this was to quantify the amount of water lost due to the environmental conditions within each animal enclosure. The equation:

$$\frac{\text{Final Amount - Initial Amount}}{\text{Initial Amount}} \times 100 = \text{Desiccation Percentage}$$

was used to calculate a desiccation percentage. This percentage was used as a correction factor in the determination of consumed food.

Spreadsheets were used to track and evaluate food consumption for each animal or group of animals included in the study. Sheet formats allowed for the evaluation of nutrient consumption of the dietary items, both individual items as well as the complete diet. Nutrient values were expressed as a percentage of total dry matter and compared to species nutrient recommendations of the Nonhuman Primate National Research Council (National Research Council, 2003). Offered diet and consumed diet were recorded separately. The nutrient composition of the offered diet versus the consumed diet were compared for the study period.

Results & Discussion

Pygmy Loris

Our results for the pygmy loris agree with its presentation for obesity. This is shown in that the pygmy loris consumed all its offered diet, and selected for no specific nutrient or ingredient, as seen in Figure 1. The pygmy loris has a diet consisting of ZuPreem canned primate (L. Huffaker, personal communication, June 27, 2016) mixed produce, yogurt, crickets, mealworms and gum Arabic. This animal also consumed part of the cardboard cup containing the gum Arabic on several occasions. Its feeding behaviors are not known in the zoo because it is nocturnal. Therefore, we cannot speculate on which food item it ate first or preferred to the rest. However, we do know the sugar to fiber ratio that was offered, which is the same as accepted. The pygmy loris consumed, on average for the 4 day intake study, 1.38 grams of sugar and 0.42 grams of fiber. In other terms, this is a sugar to fiber ratio of 3.29:1.

According to Nekaris (2010), pygmy lorises are omnivorous, and have been observed eating gums as well. In captivity, the pygmy loris has a reported history of both dental disease and obesity. This may be in part because of a diet both high in sugary fruits and because of a lack of gouging needed to properly mimic the wild behavior (Starr, 2013). However, Nekaris (2010) will admit that more research is needed before any conclusions can be made. The pygmy loris in the Philadelphia Zoo has presented with obesity, but not with any periodontal issues. The gum Arabic in its diet can lead to more natural behaviors and act as a form of enrichment (McGrew *et* *al.*, 1986). In terms of what is known of their gut morphology, we were unable to find any quantitative data. Yet, Starr (2010) did mention that they have a large caecum. This adheres to our earlier guidelines that exudativores will often have long caecums for gum fermentation. Also of note is the reported sugar to fiber ratio for the pygmy loris of 3.29:1. We identified this ratio as something we can improve. This is because the pygmy loris has accepted all its offered food, so it may accept foods that are higher in fiber and lower in sugar, so long as its nutritional requirements are still met.

Geoffroy's Marmoset

The Geoffroy's marmosets were unique in their selection for protein and fat. The Geoffroy's marmoset has a diet consisting of a mixture of gum Arabic, ZuPreem canned marmoset, fruits and insects at the Philadelphia Zoo. Their intake reflected their preference for protein as they consumed 98.4% of the ZuPreem canned marmoset diet and 100% of their crickets, superworms, mealworms and hardboiled eggs, which were the highest protein items in their diets. Similarly, these food items also had the highest fat content, besides the flaxseed oil at 99.98% fat, which was only given in small amounts daily (0.18 grams). For fruits, the Geoffroy's marmosets ate 100% of their grapes when offered. Yams were selected for next, at a rate of 67.8%. Yams were the only vegetable available that had a sugar to fiber ratio of less than 1, with sugar being at 0.5% and fiber being at 4.1% (USDA Nutrient Database, 2016). As can be seen in Figure 2, the Geoffroy's marmosets were offered 18.29 grams of sugar and 3.32 grams of dietary fiber, on average for the five day period, for a sugar to fiber ratio of 5.51:1. However, they accepted 16.16 grams of sugar and 2.50 grams of fiber, for an intake sugar to fiber ratio of 6.46:1.

It is well documented that the Geoffroy's marmoset is an exudativore that feeds opportunistically on fruit when it is available (Passamani, 2000). These observations agree with our results in that they accepted two vegetables (yams and beets) at a higher average rate than the components of the gum Arabic mix (gum Arabic, yogurt and flaxseed oil). Beyond this, the collection at the Philadelphia Zoo has presented with clinical and subclinical giardiasis. While there is little known on the microbiome of the animals in the collection as of yet; in humans, dietary modifications can help combat giardiasis (Hawrelak, 2003). The first and most relevant is dietary fiber. Humans on low fiber diets contracted giardiasis more easily than those on high fiber diets (Hawrelak, 2003). Furthermore, it is recommended that there be as little fat as possible, since the Giardiasis will depend on the bile acids released by high dietary fat (Hawrelak, 2003). Conversely, the Geoffroy's marmosets selected for fat at the highest rate, eating about 7.67 grams on average per day for the group. This could lead to the marmoset population being more easily affected, but more research is needed to determine if these same dietary correlations hold true for Geoffroy's marmosets.

Also of note, the sugar to fiber ratio was the second highest of the four species involved in the intake study. This does follow with being an opportunistic frugivore, as the fruits often exhibited the highest sugar content. In addition, the gum Arabic was mixed in a one to one ratio with yogurt, which had a sugar content of 13.8%. In essence, the gum Arabic and yogurt mix then would have a sugar content of 7.1%, which is a major contributor in the high sugar to fiber ratio. Next, there was little data to be found in regards to the gastrointestinal tracts of Geoffroy's marmosets. However, using the data known from other marmosets and the feeding ecology of these marmosets, it has been proposed that the marmoset caecum has evolved such that it can ferment gums (Ferrari & Martins, 1992). Ferrari and Martins (1992) noted that more quantitative data is still required on the gut morphologies of marmosets before any complete conclusions can be made.

Pygmy Marmoset

The pygmy marmoset is the smallest of the marmosets, yet its diet consists of the highest percentage of gums (Power & Myers, 2009). At Philadelphia, it has a diet consisting of a base Callitrichid gel diet (Mazuri, 2016), mixed produce, crickets, yogurt and gum Arabic. The pygmy marmoset displayed a preference for food items higher in sugar. It would consistently eat 100% of the offered yogurt, which had the second highest percent of total sugar at 13.8% (USDA Nutrient Database, 2016). Furthermore, it selected for its mixed produce, which contains 6.34% sugar, at a rate of 66.8%. Similar to the Geoffroy's, the pygmy marmoset ate 91.2% of its crickets and 100% of its waxworms. The waxworms are highest in both protein and fat at 38.8% and 51.4% respectively. The main diet item of the pygmy marmoset was the Mazuri Callitrchid gel, and it was selected for at the lowest percentage of 58.0%. However, this food item accounted for 70.5% of the average caloric intake. Lastly, the pygmy marmoset consumed 86.3% of the gum Arabic, which follows as gums are a major part of the wild marmoset's diet (Power, 2009). As seen in Figure 3, the pygmy marmoset was offered 5.14 grams of sugar and 0.43 grams of fiber, on average for the four day period, for an offered sugar to fiber ratio of 11.95:1. However, the accepted values were 3.15 grams of sugar and 0.31 grams of fiber, for an intake sugar to fiber ratio of 10.16:1. The pygmy marmoset was unique in that it was the only primate in the study that had a lowered accepted sugar to fiber ratio than was offered.

As with other marmosets, the pygmy marmoset has a complex cecum that is used for microbial fermentation of the gum (Coimbra-Filho *et al.*, 1980). The only quantitative data available for this species were measurements for the small intestine and colon (Power dissertation, 1991). The sample size was only one; however, the results did reflect that the colon (20 cm) was shorter than the small intestine (32 cm), yet still proportionally long. This follows as the gums are a lower quality diet material that would require fermentation in order for the nutrients to be utilized. As with most primates in captivity, pygmy marmosets are at risk for obesity, which can lead to heart disease (Eckel, 2002). The pygmy marmosets at the Philadelphia Zoo have not presented with obesity. However, due to their small portions, they can be easily overfed. Even just a gram of extra yogurt each day can be significant, as this represents a large percentage of their diet.

Coquerel's Sifaka

Similar to the pygmy marmoset, the Coquerel's sifakas accepted sugar at the highest rate. However, of the three food items it ate at 100%, garbanzo beans, peanut butter and yams, the yams and garbanzo beans had higher percentages of fiber to sugar (4.1% and 0.5% for yams and 3.85% and 2.59% for garbanzo beans respectively). The winged sumac, the local browse offered, was accepted at an 80.2% rate. This was a high percentage considering that this weight included both leaves and twigs. The high acceptance rate may be in part due to a sugar to fiber ratio of over 2:1 (5.96% sugar and 2.95% fiber). Since this represents over 24% of the diet on a dry matter basis, it is understandable that sugar makes up the largest part of their diet. Lastly, it is important to note the almost complete rejection of Mazuri leafeater large biscuits (7.2% acceptance) as opposed to the high acceptance (80.0% acceptance) of Mazuri leafeater mini biscuit. These two food items are the exact same in every way except for size and desiccation percentages. As seen in Figure 4, the Coquerel's sifakas were offered 22.12 grams of sugar and

36.36 grams of fiber, for a sugar to fiber ratio of 0.61:1. The actual intake of the Coquerel's sifaka was 18.26 grams of sugar and 23.28 grams of fiber, for a sugar to fiber ratio of 0.78:1.

The Coquerel's sifaka is a folivore that eats a complex diet (Campbell *et al.*, 2000). This is reflected in the diet it receives, which is made up of a combination of fruit, a leafeater primate biscuit (Mazuri, 2016), and browse. Furthermore, being a folivore, it requires a site of microbial fermentation for the plant material such that the cell wall can be broken down. This likely occurs in the cecum (Campbell *et al.,* 2000; Power & Myers 2009). By accepting, on average, over 200 grams of winged sumac (for the pair) each day, this component of being a folivore is met. However, there still exists the problem of a microbiome shift in these animals. Of the literature we found, only one noted and tried to explain this difference in microbiomes between captive and wild populations. Its findings reflected that a difference in environment, along with diet, development and phylogeny, play a major role in the microbiome. Another key finding of this study is that the differences in microbiomes between captive and wild animals can be as large as those found in between two populations from separate zoos (Fogel, 2015). The importance of this is that diet may not be the only factor that is affecting their microbiome.

The last result worth exploring is that of the selection for the mini biscuits versus the large biscuits. We have observed that the Coquerel's sifakas in the collection cannot seem to find a reliable way to eat the large biscuits and as a result, simply throw them on the ground after trying to bite one edge. For the smaller biscuits, they will simply eat them in a single bite. Similar results were seen with broccoli, where the larger pieces were often dropped to the ground instead of attempting to break them down into smaller pieces. The desiccation percentage for the large biscuit was 0.52% and the small biscuit had a 9.38% desiccation percentage. This means that the small biscuit gained more weight relative to the weight gained from moisture of the large biscuit. However, why exactly the small biscuit was selected for is still unknown and will require more research in the future.

Conclusion

From this study, we were able to establish baseline data in regards to the daily intake for the Coquerel's sifaka, pygmy marmoset, Geoffroy's marmoset and pygmy loris in the collection at the Philadelphia Zoo. This data was then broken down into nutritional and mineral components. The resulting sugar and fiber ratios were then calculated. In the future, the goal will be to lower this sugar to fiber ratio, in an effort to lower the risk of disease associated with high dietary sugar and low dietary fiber. Furthermore, the preference for specific nutrients (protein, sugar, fiber, fat) was calculated and graphed. We were able to find possible connections between the diets and diseases present, but more research will be needed to confirm this in the future.

As our results demonstrate, we now have a sense of the daily intake of these four primate species. Now the diets can be improved to better reflect the natural and seasonal diets of these animals. More research needs to be done examining gut morphology in all species of primates, as well as comparing the effects of captivity on gut sizes in primates. We anticipate that as more information becomes available, captive diets will continue to improve, bettering the overall welfare of animals in zoological settings.

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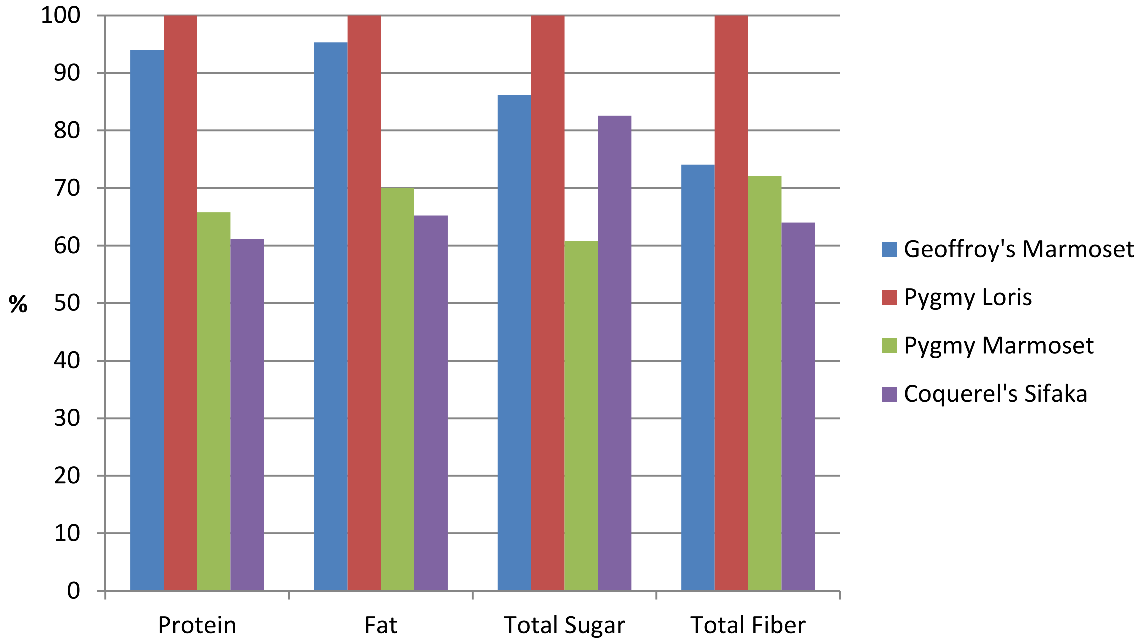

Figure 1. The percentages of major nutrients that were selected for by each of the four primate species for the complete trial dates

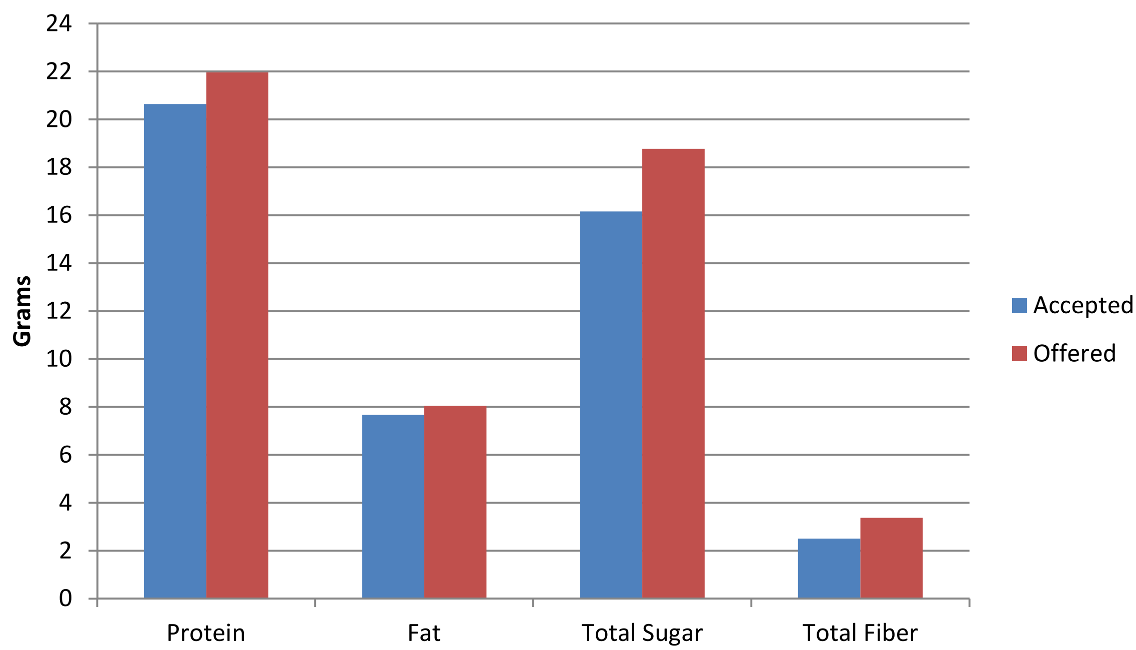

Figure 2. The average of the total trial of major nutrients offered vs. nutrients accepted (in grams) for the troop of Geoffroy's marmoset (*Callithrix geoffroyi*; n=4)

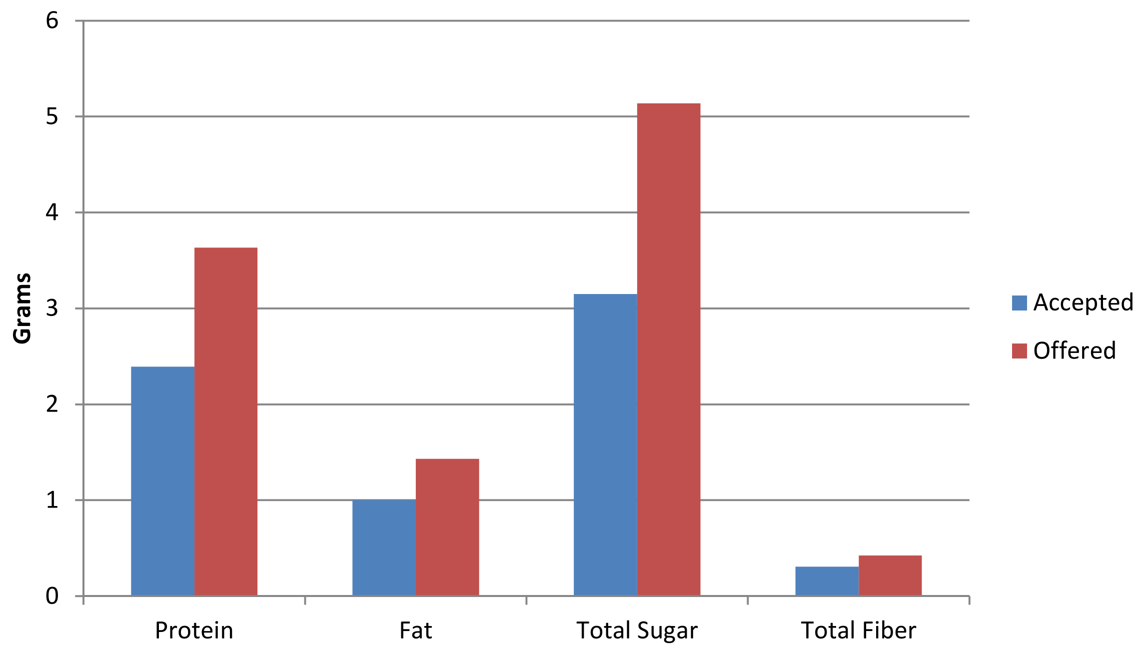

Figure 3. The average of the total trial of major nutrients offered vs. nutrients accepted (in grams) for the pygmy marmoset (*Callithrix pygmaea;* n=1)

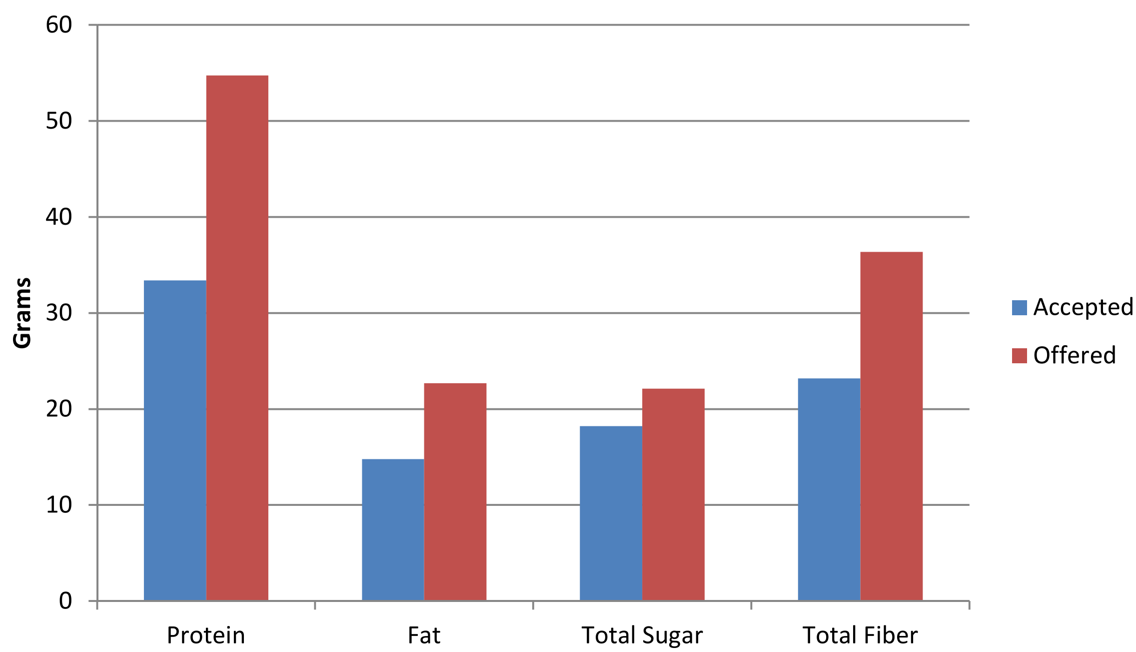

Figure 4. The average of the total trial of major nutrients offered vs. nutrients accepted (in grams) for the Coquerel's sifakas (*Propithecus coquereli*; n=2)