Fact Sheet 007
October 1997

NUTRITION ADVISORY GROUP HANDBOOK

LEAF-EATING PRIMATES: NUTRITION AND DIETARY HUSBANDRY

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Species differences in natural feeding habits and digestive system structure suggest that all captive primates should not be fed in the same manner.[28] Primates whose diets consist primarily or exclusively of leaf material possess highly developed, and delicately balanced digestive systems, which enable them to utilize this abundant food source. The order of Primates consists of several species whose natural feeding habits fall within this broad category, including apes (e.g., gorillas, siamangs), prosimians (e.g., sifakas), and monkeys (e.g., colobines, howlers). The focus of this document is the latter group: leaf-eating, or folivorous, monkeys of the families cercopithecidae and cebidae.

Although the highly specialized adaptations of leaf-eating monkeys have long been recognized, folivorous monkeys often are fed diets that are similar to those fed to primate species that are not primarily folivorous and/or do not have specialized digestive adaptations.[15,30] This may have contributed to the high incidence of gastrointestinal disorders among captive specimens.[3,4,12,13,14,15,16,27] Success in maintaining captive populations has been widely mixed, and to date, is species-specific.[6] Appropriate diet composition and presentation may be identified as key features in the successful maintenance and propagation of folivorous monkeys under captive conditions.

Based upon the feeding strategies and nutrient composition of foods selected by free-ranging animals,[8] and their gastrointestinal anatomy, the objectives of a captive feeding program for leaf-eating monkeys are to increase dietary fiber, limit the amount of fermentable carbohydrates both overall and at a single feeding, and disperse feedings in small portions throughout the animals' day.

Gastrointestinal Adaptations to Folivory

Although the extent of herbivory demonstrated by a given species is variable, monkeys which specialize in consuming leaves exhibit several gastrointestinal adaptations to this diet, including enlargements of the stomach and/or the hindgut to accommodate symbiotic microorganisms.[19,24] These beneficial microorganisms digest plant fiber (primarily cellulose and hemicellulose) using enzymes that are lacking in the "host" animal. Fermentation of plant fiber and other compounds results in the production of several fermentation end-products, including volatile fatty acids that can be absorbed and used as an energy source. Microbial fermentation occurs in the large sacculated forestomach of colobines (e.g., colobus monkeys, langurs). The colobine stomach has four parts: two highly sacculated portions followed by a long tubular gastric portion, and a short pars pylorica.[5,18] The hindgut includes a long sacculated colon and cecum of moderate size. The presence of microbial organisms[2] and extensive microbial fermentation,[2,18] demonstrate the ruminant-like digestion possessed by colobine primates.[23] The pH of the colobine foregut has been reported to be between 5.0 and 6.7 in langurs[2] and about 7.0 in colobus.[18] There also may be considerable microbial fermentation in the cecum and colon of colobines.[22,28] The stomach of the mantled howler monkey exhibits a great deal of complexity when compared with other cebids,[5] yet microbial fermentation of ingested plant material at this site has not been confirmed. The primary sites of microbial fermentation in the howler monkey occur in the hindgut, specifically the sacculated, hook-shaped cecum and simple colon.

The presence of bacteria in these fermentation sites is not sufficient, by itself, to ensure appropriate digestion of ingesta. The species distribution of microbial populations is affected by the substrates (i.e., ingested food) available. By analogy to ruminant species, if a primate has been fed dietary items unlike those consumed by its recent ancestors in the free-ranging state (e.g., high sugar fruits, high fat/starch complete feeds), the types and numbers of bacteria within the fermentation sites may be adversely altered. A consequent gradual change in foregut pH may cause a decline to a debilitated state in which the majority of beneficial bacteria are presumed lost (i.e., disbiosis).

Food Quantities Consumed

While natural feeding habits and gastrointestinal adaptations must be considered, individual food intake is also important baseline information needed when formulating diets for captive animals. Food intake varies with a number of factors, including energy density and digestibility of the diet, and physiological status of the animal. Elevated dietary fiber and moisture levels may stimulate increased food intakes. Water intake of free-ranging animals may be met by the consumption of high moisture food items, but in captivity, the inclusion of dry foods necessitates *ad libitum* access to clean water. Daily dry matter intakes of selected captive folivorous monkeys are summarized in Table 1.

Those institutions that seem to have the greatest success with long-term maintenance of captive folivorous monkeys are those that have addressed their specialized needs.[9] Husbandry practices should promote a healthy microbial population within the gastrointestinal tract. Delivery of adequate levels of plant fiber, to maintain normal microbial fermentation, is a basic part of this strategy. There are three primary methods of increasing the amount of fiber in these animals' diets: 1) use of higher-fiber manufactured feeds, 2) reduction or elimination of produce items that contain readily fermentable carbohydrates and increasing produce that delivers higher fiber concentrations, and 3) inclusion of

browse.

Higher-Fiber Complete Feeds

A common approach to feeding captive primates increased fiber is the replacement of commercial primate biscuits containing a low concentration of fiber (10-19% neutral detergent fiber [NDF], 5-7.5% acid detergent fiber [ADF]) with a higher-fiber product (25% NDF, 15% ADF). The lower fiber commercial primate diets were designed originally for omnivorous primates, such as macaques. Use of commercially produced higher-fiber primate diets is a fairly recent option, resulting from the response of zoo feed manufacturers to scientific evidence and demands of animal care staff. The ingredients supplying fiber vary among manufacturers and products. Although claims may be made regarding the benefits of one fiber source over another, no controlled studies have been conducted to support those claims.

Animal managers and caretakers should be aware that some leaf-eating monkeys may initially be reluctant to accept new higher-fiber diets in place of traditional primate biscuits. With patience and persistence, most individuals can be effectively converted to higher fiber biscuits.

Most nutritionally "complete" diets are formulated to comprise no less than 50% (as-fed basis) of the total diet consumed by an individual animal. As most zoo primates are housed in groups, it may be necessary to feed these diets at a higher level (e.g., 65%), to ensure that all individuals within the group receive the minimum quantities necessary to deliver adequate concentrations of limiting nutrients.

Browse

Dietary fiber concentrations may also be increased by offering browse. Browse is defined as woody plant material, including leaves and stems that is provided as a food source. Browse is sometimes used as a supplemental food for leaf-eating primates.[11,29] The contribution of browse is variable depending upon local growing conditions and economic considerations,[17] but its use is increasing as attempts to offer more "natural" diets grow in popularity. The types of plant material offered also are widely variable, from indigenous species to easily grown tropical plants. Plant species that are consumed by conspecifics in the wild would be especially appropriate, but have not been widely used.

Special precautions should be taken when offering browse to captive primates. Nutrient contributions of the browse to the total diet should be determined,[21] and the impact of seasonal variability, fertilization, and pesticide spraying of browse plants should be assessed. Additionally, substances that inhibit herbivory such as secondary plant compounds (i.e., tannins, alkaloids, saponins) can be present within these plants.[28] Animals that are offered these plants should be considered naive to such defenses. As this approach to feeding becomes more common, reports of deaths directly attributable to the consumption of browse have increased.[10,14,25,16] This is an unfortunate demonstration of the mechanisms that plants have developed for self protection, as well as the consequences of relying upon "nutritional wisdom" when offering naive animals novel foods. Browse can be offered in an upright fashion, which stimulates natural feeding behavior. Based upon the type of plant material, and feeding habits of the primates consuming the offered material, it may be necessary to secure the plant material in a container. For example, browse sections may be placed in an upright section of PVC tubing which has been capped on one end. Once the material has been properly secured in the

container, animal access to the bark and stem are restricted. These portions of the plant have most commonly been the "matrix" for phytobezoars, which formed physical obstructions in the gastrointestinal tract of affected individuals.[16] For these reasons, it is important to monitor the parts of the plants that are consumed. Due to the variable seasonal availability of browse in specific geographic regions, and the sensitivity of captive folivores to changes in diet, caretakers should balance the potential benefits and possible negative features of including this food in the diets of folivores.

Commercially Available Produce

The selection of commercially available produce for captive primate diets has historically been guided by human tastes, and perceptions of what individual primates may "like". Although bearing similar names (e.g., fruits), the nutrient composition of cultivated plant foods is generally quite different from that of plant foods consumed in the wild.[9] Due to the elevated concentrations of simple sugars and other carbohydrates, and lower levels of dietary fiber found in commercially available fruits, fruits should be eliminated or significantly reduced in diets offered to captive folivores. Crandall[7] indicated that problems surrounding the captive husbandry of howler monkeys could be solved, in part, by a diet providing sufficient leafy bulk. Produce should be considered more a supplemental, rather than a primary, portion of the diet. Although these items do allow the caretakers to provide diversity or variation in a captive animal's diet, the items selected for inclusion must be strictly defined. Produce items included in a folivore's diet should be restricted to leafy greens and higher-fiber vegetable material (e.g., broccoli, celery).

Recommendations

The ability, both financial and logistical, to consistently supply an appropriate diet for folivorous monkeys is as important as any considerations of exhibit design, housing, or group social dynamics. The animal care staff should keep in mind that when feeding a folivorous monkey, especially those with foregut fermentation, they are feeding a bacterial colony in the gut that in turn feeds the "host" animal via the end products of the fermentation process. All dietary changes must be made gradually, and progression through such changes should be based upon animal response. This includes the seasonal introduction and withdrawal of browse in climates that can not support year-round production.

Free-ranging leaf-eating monkeys spend large portions of the day foraging. This strategy of dispersing feeding bouts over time reduces the sudden influx of rapidly fermentable material. Mimicking this natural feeding strategy through an increased frequency of feeding (i.e., six times daily), in conjunction with use of the appropriate dietary components previously discussed, is an important feature of dietary husbandry of these selective feeders.[20] This gradual distribution of smaller "meals" throughout the day promotes a steady rate of fermentation, and helps ensure adequate dispersal of food among individuals housed in a group. This approach has proven to be a key component in the dietary management of those folivores that exhibit the highest sensitivity to changes in captive diet (e.g., douc langurs). When committing to house these specialist primates, managers should anticipate the need for labor to provide this level of care.

In summary, a suggested approach to the feeding of captive folivorous monkeys includes:

1. Use a higher-fiber (15% ADF) primate biscuit as at least 65% (as-fed basis) of the offered diet.
2. When using produce, reduce or eliminate commercial fruits, and increase leafy green vegetables and higher fiber vegetable material.
3. If browse plants are fed, make sure that they are not toxic and are presented in an appropriate manner.
4. Distribute offered foods in small quantities over several feedings (> 3) per day.

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Table 1. Mean body weight (BW) and mean dry matter intake (DMI) of several folivorous monkeys fed nutritionally complete, higher-fiber diets.[8]

Species	Diet[a]	*n*	BW (kg)	DMI (g/d)	DMI (% BW)
Hindgut Fermenters					
Black howler	ADF15	3	8.11	128.0	1.76
	ADF30	3	8.11	185.1	2.55
Mantled howler	ADF15	2	5.85	141.0	2.39
	ADF30	2	6.45	131.5	2.03
Red howler	ADF15	2	8.32	130.6	1.61
	ADF30	2	8.03	157.7	1.97
Foregut Fermenters					
Black & white colobus	ADF15	1	10.90	154.8	1.42
	ADF30	1	10.70	153.8	1.44
Douc langur	ADF15	1	12.10	428.9	3.55
	ADF30	1	11.75	391.1	3.33
Francois' langur	ADF15	5	5.96	182.4	3.16
	ADF30	5	5.94	176.6	3.18

[a]Diet consumed was exclusively one of two higher-fiber primate biscuits designated as ADF15 and ADF30 based on acid detergent fiber content.