Fact Sheet 013
April 2003

NUTRITION ADVISORY GROUP
HANDBOOK

CALLITRICHIDS: NUTRITION AND DIETARY HUSBANDRY[a]

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Meeting the nutritional needs of Callitrichids is essential to their survival and reproduction in captivity. Development of appropriate dietary guidelines involves information on 1) feeding ecology, 2) published nutrient requirements, often from studies of laboratory primates, 3) food preferences, and 4) foods available in zoos for diet formulation. This monograph is meant to provide a general overview of the feeding of Callitrichids. Several SSPs have published husbandry manuals for individual species, including species-specific recommendations. Please refer to these for additional and sometimes more specific information on nutrition and feeding.

[a]Adapted from the AZA Callitrichid Husbandry manual. AZA Callitrichid SSP.

Feeding Ecology

Information on feeding ecology of Callitrichids has increased significantly in recent years. This has expanded our knowledge of food ingested in the wild, but most studies provide qualitative information rather than detailed quantitative data on amounts of food and nutrient concentrations in the foods selected.

It has been reported that, in natural ecosystems, larger Callitrichid species tend to select insects and fruits whereas the smaller species tend to select insects and exudates (gums, saps, and latex). Insect foraging appears to be a primary food adaptation of Callitrichids.[29] Emperor tamarins (*Saguinus imperator*) are primarily frugivorous and insectivorous, with grasshoppers as the main insect-food item. Their diet also may include exudates, nectar, flowers, and other plant parts. In the dry season when fruit is scarce, emperor tamarins are often intense nectar feeders, [74] although Rosenberger[66] noted that they may lose as much as 15% of their body weight when consuming large quantities of nectar. Additionally, moustached (*Saguinus mystax*) and saddle-back (*Saguinus fuscicollis*) tamarins spend up to 31% of feeding time on nectar during the dry season.[28] The diet of moustached tamarins includes about 14% insects as determined by time spent foraging. Both saddle-back and moustached tamarins consume water and prey from bromeliads[52] as do golden lion tamarins (*Leontopithecus rosalia*).[29] Some may consume up to 38 species of insects, with some insects weighing over 8.5 grams.[52] The diet of black-handed tamarins (*Saguinus midas niger*) has been reported to be largely frugivorous (87.5%) but also includes arthropods and plant exudates.[55] Seeds up to 1 cm in diameter or 2 cm in length have been found in their feces. Golden-handed tamarins (*Saguinus midas midas*) similarly ingest fruit and insects, but Pack et al.[56] noted important seasonal differences in foods consumed. Knogge[40] studied seed ingestion and dispersal in both saddle-back and moustached tamarins in the wild. He noted that 95% of fecal samples contained remnants of 88 fruit species out of a total of 155 fruit species eaten. Seeds ingested and defecated ranged from 0.6 mm to 2.6 cm in length. Details were provided on seed species ingested and gut passage time.

Golden-mantled tamarins (*Saguinus tripartitus*) ingest fruit, gums, and Tettigoniid insects.[35] Moustached tamarins also consume fruit seeds and pass these undigested.[34] Golden lion tamarins have been observed to feed largely on fruit and small prey, switching to nectar when fruit is scarce.[16] Interestingly, moustached and saddle-back tamarins also foraged on frogs, lizards, and occasionally nestling birds.[36] Similarly, Smith[70] studied both saddle-back and moustached tamarins in the field. Both species were found to capture katydids (Tettigoniids), stick insects (Proscopids), spiders (Araneids), as well as lizards (Squamatids) and frogs (Anurids), with katydids as the main prey. A review of vertebrate prey consumed by a variety of marmoset, tamarin, and a lion tamarin species[17] included frogs, lizards, nestling birds and eggs, and mammals. Of note is a report by Townsend[75] of a wild-caught pet pygmy marmoset (*Cebuella pygmaea*) catching and killing a bird.

Pygmy marmosets are arboreal, rarely coming to the ground. The pygmy marmoset is classified as an exudate feeder and insectivore. It feeds on exudates by gouging holes with its lower incisors on the major branches of trees and the stems of vines.[39, 64] Favorite insects are grasshoppers, spiders, and butterflies. Ramirez et al.[64] noted that pygmy marmosets spend 67% of their total feeding time in the investigation and procurement of exudates and 33% of feeding time foraging for insects. Fruit, buds, flowers, and nectar also were consumed, but constituted a minor portion of the diet.

Smith[69] analyzed gums ingested by saddle-back and moustached tamarins in the wild, and found that they were relatively high in calcium. He suggested that calcium in gums might be important to balance the generally high concentrations of phosphorus found in the remainder of the Callitrichid wild diet. However, when seasonal consumption data were examined, he found that gums were not uniquely sought as a supplement during gestation or lactation. Bare-ear marmosets (*Callithrix argentata*) have been reported to be active mainly where gum-producing trees are found.[1] Correa et al.[13] suggested that reports of the proportions of food items ingested in the wild are related to the supplies of foods available at the time of observation. Both buffy-headed (*Callithrix flaviceps)* and buffy tufted-ear (*C. aurita*) marmosets ingested different amounts of fruit, exudates, and prey in different years, generally in proportion to food availability. Feeding budget studies indicated that buffy tufted-ear marmosets spent 50.5% of their time feeding on gums, 11% on fruits, and 38.5% on prey items.[42] The insect types ingested included 33% caterpillars, 5% katydids, and 4% homopterans. Geoffroy's marmosets (*Callithrix geoffroyi*) ingested gums in two periods during the day, mainly early in the morning but also in the afternoon.[57] Power and Oftedal[60] compared digestibility and digesta transit time (expressed as time to first appearance [TFA] of an indigestible marker) of diets containing gum or no gum fed to pygmy and common marmosets, and cotton-top, saddle-back, and golden lion tamarins. TFA was longer in marmosets when gum was added to the diet, and digestibility of gum-containing diets was equal to that of gum-free diets. However, addition of gum to diets fed to tamarins lowered digestibility. These observations suggested to these researchers that marmosets are adapted to gum digestion.

Diets may vary considerably within species, as well as among species, in types of foods consumed. This diet variability may be a consequence of seasonal changes in food availability and distribution. *Saguinus* species have been grouped according to foraging strategies. Groupings include 1) seasonal exudate feeding, occasionally from tree trunks, 2) insects taken from bark surfaces and tree trunks used as resting platforms by terrestrial prey, 3) bark stripping for insects and small vertebrates, and 4) tree gouging year round for exudates.[29] Some moustached tamarins may consume soil, presumably for its mineral content.[33] Passamani[57] found that diet was related to season, with increased numbers of prey items available during the wet season. The preliminary results of a long-term study on semi-free ranging common marmosets found that the number of prey species obtained from the outdoor habitat increased exponentially over four years.[67] The list included gastropods, worms, arachnids, rodents, and a very large range of insect and bird species.

Callitrichids share food with young. Captive black lion tamarins (*Leontopithecus chrysopygus*) obtained most of their solid food from group members prior to 15 weeks of age but sometimes continued to receive food up to six months of age.[20] Rapaport[65] suggested from a study on captive golden lion tamarins that adults alter their feeding behavior to teach immature tamarins which items are suitable foods.

Callitrichids are small in comparison to other New World primates; with body masses generally ranging from 105 to 700 g.[29] Their claw-like nails allow clinging while foraging. Dentition has been used to categorize them as marmosets (short-tusked for gouging bark) and tamarins (long-tusked). [21] These features are correlated with feeding strategy. GI-tract morphology of Callitrichid species has been associated with the extent of exudate consumption, specifically of gums. Presumably, a more complex GI-tract benefits gum digestion. Common marmosets (*Callithrix jacchus*) feed on exudates (as well as fruits and other foods) and possess a cecum (with internal strictures) that is more complex than that of tamarins. These complexities may increase residence time both of digesta and fermentative microbiota, favoring anaerobic digestion.[29] Bare-ear marmosets (*C. argentata emiliae*) also have a complex cecum to help process gums.[21] These GI-tract features are less well developed in the golden lion tamarin.[29]

Published Nutrient Requirement Data

Very few studies have been conducted to establish quantitative nutrient requirements of Callitrichids. The National Research Council[51] has summarized much of the published data. Even though information from controlled studies was insufficient to estimate quantitative requirements for other than energy, protein, iodine, vitamin D, and vitamin E for Callitrichids, estimated adequate concentrations have been proposed for 30 nutrients in conventional-ingredient diets intended for post-weaning nonhuman primates.

Energy. The amount of food that must be consumed per day for maintenance is related to the digestibility of that food. The apparent digestibility of the gross energy (GE) in a laboratory diet fed to adults of five Callitrichid species ranged from 71 to 86%.[59] Power[59] concluded that digestible energy (DE) requirements (169-310 kcal/BW_{kg}/day) appeared to be inversely correlated with body size except for pygmy marmosets, which had the smallest body size (0.133 kg) but digested 84% of the GE in their diet and had a daily DE requirement of 208 kcal/BW_{kg}. Pygmy marmosets have been shown to have one of the lowest basal metabolic rates among the simians, 98 ml O_2/hr at 27-34° C.[30] Genoud et al.[30] suggested that this low metabolic rate may be related to gum ingestion.

Daily requirements for metabolizable energy (ME) per unit of body weight tend to be higher for maintenance of adult marmosets and tamarins than for adults of larger nonhuman primates. Reported ME requirements for Callitrichids range from 142 to 232 kcal/BW_{kg}/day.[7,49] Given that twinning is common in Callitrichids, energy costs during reproduction should be relatively high. Nievergelt and Martin[53] observed captive common marmosets, both male and female, during pregnancy and lactation. Females were found to increase their energy intake by up to 100% and lost weight during lactation. Males helped the females by carrying the infants for significant periods of time, but their energy intakes and body weights did not change. Nievergelt and Martin[53] concluded that subtle changes in behavior during reproduction may result in some reduction of the male energy budget.

Protein. In 1978, the NRC[50] stated that New World primates need higher dietary concentrations of protein than their Old World counterparts. Because protein requirements of fewer than 10 species have been studied, and there are over 100 species of New World primates and over 150 species of Old World primates, such a generalization seems unwarranted. Further, more recent evidence does not support this conclusion.[51,54] Protein requirements (from casein) for weight maintenance of adult saddle-back tamarins were shown to be 7.3% of dietary dry matter (DM) or 2.8 g/BW_{kg}/day.[25] Protein requirements (from soy protein concentrate) for maintenance of nitrogen balance in adult common marmosets were 6.6% of dietary DM or 2.5 g/BW_{kg}/day.[25] Flurer and Zucker[25] found that marmosets consumed their feces when diets contained less than 6% protein or lacked one or more amino acids.

Protein requirements for growth of Callitrichids on purified diets have been estimated to be 18% of dietary DM for the very young, gradually declining to 12%.[51] Protein contributes approximately 19% of the GE in the milks of common marmosets, pygmy marmosets, and golden lion tamarins.[62] For comparison, Ausman et al.[4] have shown that 20.8% protein (from casein) in dietary DM was required for 2-3 week old squirrel monkeys (*Saimiri sciureus*), declining to 10.0% at 2-3 months and to 8.1% at 9 months.

There have been no studies of protein requirements of pregnant or lactating Callitrichids. It should be noted that protein requirements are linked to the array and quantity of essential amino acids, the digestibility of the protein, and the presence of secondary plant compounds, such as tannins, that may influence protein availability and use. Taurine, an α-aminoethanesulfonic acid, is needed for proper neurological development of young primates, but its requirement as a dietary essential for adults has not been established.[71] Tardif et al.[73] found no difference in growth and reproduction between common marmosets fed purified diets providing 15% or 25% protein (as fractions of estimated dietary ME concentration). Estimated adequate concentrations of protein for post-weaning growth and reproduction of nonhuman primates range from 15 to 22% in the DM of diets containing conventional feed ingredients.[51]

Iodine. Iodine deficiency has been observed in common marmosets fed a diet composed of natural ingredients and containing 0.03 μg I/g of DM.[41] Plasma thyroxine concentrations declined and plasma thyroid-stimulating hormone concentrations increased. Thyroid glands were hypertrophied and hyperplastic. Cerebral brain-stem cell size was reduced in offspring from second pregnancies. These signs were prevented by providing 0.65 μg I/g of DM. Lower supplemental levels of iodine were not tested. Estimated adequate iodine concentrations in diets containing conventional feed ingredients are 0.35 mg/kg DM.[51]

Vitamin D. In the few species of New World primates that have been studied, vitamin D_2 appears less active than vitamin D_3. Well-controlled studies comparing the two vitamin forms in Old World primates have not been conducted, although there are anecdotal reports that rhesus and other macaques provided only vitamin D_2 showed no evidence of metabolic bone disease.[51] It has been proposed [5,72] that marmosets and tamarins may require higher levels of vitamin D_3 than other New World primates because of target-organ receptor resistance to the active form of the vitamin. Flurer and Zucker[23] found that vitamin D_3 at 2,000 IU/kg of air-dry diet supported (apparently normal) serum 25(OH)D concentrations of 12-120 ng/ml in saddle-back tamarins. To establish baseline concentrations for assessing vitamin D status of captive Callitrichids, Power et al.[61] analyzed blood from 18 wild-caught, cotton-top tamarins. Serum concentrations of 25(OH)D ranged between 25.5-120 ng/ml, which they noted was considerably higher than the range of 10-55 ng/ml found in normal humans. It is noteworthy that Goeldi's monkeys were found to have lower serum vitamin D metabolite concentrations than other New World monkeys.[15] However, Crissey et al.[14] also reported that renal dysfunction in this captive colony of Goeldi's monkeys may have affected the vitamin D metabolite values.

Commercial diets for Callitrichids can contain very high levels of vitamin D_3. These high levels have led to vitamin D toxicity in pacas (*Cuniculus paca*) and agoutis (*Dasyprocta aguti*) housed in mixed species exhibits with Callitrichids.[38] To investigate suitable dietary levels of vitamin D_3, Ullrey et al.[76] compared the health status of cotton-top tamarins (*Saguinus oedipus*) fed higher versus lower levels of vitamin D_3. The levels compared were 2,500 IU vitamin D_3/kg DM in a zoo colony, and 26,000 IU vitamin D_3/kg DM in a laboratory colony. The lower levels fed in the zoo colony supported growth, reproduction, serum 25(OH)D concentrations (48-236 ng/ml) similar to those in wild-caught animals, and apparent good health. The levels of 26,000 IU/kg DM fed in the laboratory colony resulted in a larger range of serum 25(OH)D concentrations (11-560 ng/ml) but no indications of any improved health status. In fact, evidence of colitis was common, although this might have been associated with the stresses of housing and handling. NRC[51] estimates of requirements in purified diets are 2,400 IU vitamin D_3/kg DM. Estimated adequate concentrations in diets containing conventional feed ingredients for post-weaning nonhuman primates are 2,500 IU/kg DM, acknowledging that there are anecdotal reports of higher requirements for Callitrichids under certain circumstances.[51]

Vitamin E. Callitrichid requirements for vitamin E have been studied only in the common marmoset. To support normal plasma α-tocopherol concentrations and inhibit hydrogen peroxide-induced hemolysis, 4 to 48 mg of D-α-tocopherol/kg of purified diet were required.[43] When fish oils were added to a purified diet, requirements increased to over 95 mg of D-α-tocopherol/kg.[31] Young common marmosets had normal plasma α-tocopherol concentrations on 130 IU or less of α-tocopherol/kg of purified diet.[11] The NRC[51] estimated that the requirement for vitamin E in a purified diet is in the range of >95-130 mg all-*rac*-α-tocopheryl acetate/kg DM. The estimated adequate vitamin E concentration in diets containing conventional feed ingredients was set at 100 mg all-*rac*-α-tocopheryl acetate/kg DM.

Other nutrients. Folic acid deficiency has been produced in common marmosets.[18] Deficiency signs included weight loss, alopecia, diarrhea, megaloblastic anemia, leucopenia, granulocytopenia, and lesions of the oral mucosa (bilateral angular cheilosis). The stomatitis appeared to result from inadequate maturation of the epithelial cells, subsequent ulceration, and secondary infection.[19] The deficiency was prevented by adding 3.3 mg of folic acid/kg of diet, although the minimum folic acid requirement was not defined.

Vitamin C is a dietary essential for common marmosets, with deficiencies resulting in hemorrhages, loss of density about the periodontal ligament, and declines in physical mobility, red cell count, hematocrit, and mean red cell volume.[19,26] To maintain blood ascorbate concentrations above the renal threshold, Flurer et al.[22] concluded that 20 mg ascorbic acid/BW_{kg}/day (500 mg/kg diet) was required. This concentration assured excretion of a small amount of ascorbic acid in the urine. When compared to common marmosets on the same diet, saddle-back tamarins had significantly lower circulating ascorbate levels, intimating that there may be a species difference in need.[26] Stress appears to increase the rate of ascorbic acid metabolism, and there was some evidence of a difference in susceptibility to stress between the two species.[24,27] It should be noted that stable forms of vitamin C were not used in these studies nor were the diets analyzed for vitamin C at the time of feeding. Loss of vitamin C during diet manufacture and storage could lead to an overestimate of the requirement.

Zinc deficiency was reported in moustached marmosets fed a commercial diet, which was said to contain 150ppm of zinc, although this value was not confirmed by analysis. When 40 ppm zinc was added to drinking water, the deficiency signs (alopecia) were alleviated but returned when drinking water was supplemented with 80ppm zinc.[10] This illogical result was not explained.

Diets high in iron can lead to hepatic hemosiderosis in common marmosets.[45] Young adults were given diets containing either 100 or 500 ppm of iron. After seven months, the 500 ppm level was lowered to 350 ppm, due to the death of one individual. The mean liver iron concentration in marmosets fed the high-iron diet was 6,371 μg/g DM, whereas the marmosets fed the low-iron diet had a mean liver iron of 622 μg/g DM.

Qualitative and quantitative evidence of the need of Callitrichids for other nutrients appears not to have been published. Estimated adequate nutrient concentrations (DM basis) in diets containing conventional feed ingredients and intended for post-weaning nonhuman primates are shown in Table 1.

Table 1. Estimated adequate nutrient concentrations (DM basis) in diets containing conventional feed ingredients intended for post-weaning Callitrichids, accounting for potential differences in nutrient bioavailabilities and adverse nutrient interactions, but not accounting for potential losses in feed processing and storage (adapted from NRC[51]).

Nutrient	Concentration	Nutrient	Concentration
Crude protein, %	15-22[a]	I, mg/kg	0.35
Essential n-3 fatty acids, %	0.5[b]	Se, mg/kg	0.3
Essential n-6 fatty acids, %	2[c]	Trivalent Cr, mg/kg	0.2
Neutral detergent fiber (NDF), %	10[d]	Vitamin A, IU/kg	8,000
Acid detergent fiber (ADF), %	5[d]	Vitamin D_3, IU/kg	2,500[g]
Ca, %	0.8	Vitamin E, mg/kg	100[h]
Total P, %	0.6[e]	Vitamin K, mg/kg	0.5[i]
Non-phytate P, %	0.4	Thiamin, mg/kg	3.0
Mg, %	0.08	Riboflavin, mg/kg	4.0
K, %	0.4	Pantothenic acid, mg/kg	12.0
Na, %	0.2	Available niacin, mg/kg	25.0[j]
Cl, %	0.2	Vitamin B_6, mg/kg	4.0
Fe, mg/kg	100[f]	Biotin, mg/kg	0.2
Cu, mg/kg	20	Folacin, mg/kg	4.0
Mn, mg/kg	20	Vitamin B_{12}, mg/kg	0.03
Zn, mg/kg	100		

[a]Requirements for growth of young and for lactation are best met by the higher concentrations in this range. Required protein concentrations are markedly affected by amounts and proportions of essential amino acids. Taurine may be a dietary essential through the first postnatal year.

[b]Requirement can be met by a-linolenic acid. Required concentration may be lower when supplied by eicosapentaenoic or docosahexaenoic acids.

[c]Requirement can be met by linoleic or arachidonic acids.

[d]Although not nutrients, NDF and ADF at or near indicated concentrations appear to be positively related to gastrointestinal health.

[e]Some of P in soybean meal and certain cereals is bound in phytate and poorly available.

[f]Iron-storage disease (hemosiderosis) is a potential problem, particularly when large quantities of fruits are offered, presumably because citrate or ascorbate promote iron absorption. Under these circumstances, it may be important to limit iron to near or slightly below this concentration. Particular attention should be given to iron concentrations in phosphorus and calcium supplements and to selection of sources that are low in this contaminant.

[g]There are anecdotal reports of higher vitamin D_3 requirements under some circumstances, perhaps related to impaired absorption in individuals with colitis.

[h]As all-*rac*-α -tocopheryl acetate.

[i]As phylloquinone.

[j]Niacin in corn, grain sorghum, wheat, barley, and their byproducts is poorly available unless they have undergone fermentation or wet-milling.

[k]Ascorbyl-2-polyphosphate is a vitamin C source that is biologically available and quite stable during feed processing and storage.

Foods Used in Zoos and Research Colonies

To make judgments concerning the adequacy of foods used in zoos, knowledge of the quantity of nutrients consumed is of primary importance. For the most part, however, these data are not available. In a 1985 publication,[12] it was stated that a variety of foods was being offered in marmoset research colonies and that the problem of marmoset wasting syndrome had been nearly eliminated. Most facilities fed a commercial diet supplemented with other foods, such as insects, small vertebrates, and produce. At the time of this NAG publication, similar commercial products are still available. It appears quite possible to maintain and breed Callitrichids in captivity on a combination of manufactured diets and other commonly fed items. The level of protein reported in 1985[12] to be adequate was 20% (DM basis) with a comment that this may be above true requirement levels. Fat levels were about 7% with carbohydrate at 61.4% and ash at 5.3% (DM basis).

One study of a diet fed to captive Geoffroy's marmosets involved calculation of the nutrient content of a mixed diet with respect to possible nutritional problems found in the collection.[63] Because the animals were housed both singly and in groups, the data were not readily applicable to judgments of dietary adequacy. Theoretically, the diet met the 1978 NRC[50] recommended nutrient levels for New World primates and appeared adequate for other species. The authors suspected the levels of protein and some minerals were inadequate for these particular marmosets.

Consideration should be given to differences in composition between categories of foods consumed in the wild and those categories of foods fed in zoos and research laboratories. Studies of foods consumed by free-ranging primates indicate that they may be considerably different in nutrient content from those same categories of foods in captivity. Generally, fruits in the wild are higher in fiber and lower in sugars than fruits cultivated for human use.[9] Also, fruits consumed in the wild may be primarily unripe, while ripe fruits are usually fed in zoos. Ripening increases the sugar level, and rapid gastrointestinal fermentation may partially explain why fresh fruit fed in zoos sometimes causes loose stools. Additionally, free-ranging Callitrichids consume many other foods, including exudates and various species of insects. This variety of food items is not commercially available to institutions.

Some captive Callitrichids may be offered neonatal mice, or "pinkies", as a protein source. Pinkies carry a serious risk of a rare but rapidly progressive viral hepatitis from consumption of liver and spleen tissue containing lymphocytic choriomeningitis virus (LCMV), an arenavirus.[8,46-48]

Marmoset pellets, which contain cereal grains, are standard fare for many captive Callitrichids. Two recent studies[32,68] indicate, however, that medically significant levels of IgA-gliadin antibodies can be found in marmosets and tamarins whose diets contained cereal grain proteins.

Food Preferences

As mentioned previously, the food most consumed by free-ranging animals may not be that most sought but that most available. There also may be differences in food choice based on varying physiologic conditions. Often there are large day to day fluctuations in food consumption within and among animals that are not readily explained.

Foods in the diets of captive Callitrichids are limited as to types and varieties as compared to options in the wild. Studies with several laboratory species have shown that foods are not necessarily selected on the basis of nutrient content. Instead, Callitrichids given a limited variety of succulent foods may select those that are high in sugar, high in fat, or simply novel.[63] Thus, it is important to offer foods that complement each other nutritionally.

There are a number of publications listing nutrient concentrations in commonly offered foods such as produce.[58] Other publications provide information on nutrient concentrations in insects.[2] State and federal regulations require provision of the guaranteed analysis of packaged commercial products for a limited number of items, such as protein, fat, and fiber, but this information does not generally include concentrations of vitamins and minerals. Many times, manufacturers will provide these values upon request, or the product can be chemically analyzed.

Using published research on requirements, the NRC[51] guidelines, data on the feeding ecology of wild Callitrichids, and the nutrient content of foods available in zoos, it is possible to formulate diets that are appropriate for captive Callitrichids.

Formulation of Appropriate Diets

When formulating diets for captive Callitrichids, flexibility is needed to accommodate animal preferences and variations in weight, exercise, physical condition, environment, and behavioral considerations, as well as commercial availability of food items. Thus, guidelines for nutrient content and food categories rather than recommendations for specific food items in set quantities may be appropriate. The guidelines below allow for flexibility in diet formulation while assuring that a nutritionally adequate diet will be offered.

Foods to be included in the diet, means of food presentation, and enclosure design all may be viewed as components of environmental enrichment. As long as target dietary nutrient levels are met, food presentation can be altered to fit behavioral and enrichment needs. Natural feeding strategies might be mimicked by offering diets in feeding tubes, fashioned like bromeliads, or in “flaky” substrates, to reflect searching for food under bark. Gums can be offered in ways that encourage substantial activity. [37]

Dietary Recommendations

Callitrichids should be fed at least twice per day. The interval between morning and afternoon feeding should be between 4 ½ and 6 ½ hours. More food should be provided in the morning (or more active period) than in the afternoon (less active period), though the same food categories should be offered. Since marmosets spend much of their time in the wild foraging, food might be offered multiple times throughout the day, and the food scattered to promote foraging.

When consumed in its entirety, the diet should contain the nutrient concentrations presented in Table 1 (DM basis). It is possible to achieve the nutrient levels in Table 1 by offering a diet consisting of the indicated food items (or food groups) in percent by weight, as fed.

For flexibility, three diets are presented. Each of these diets meets or exceeds the target nutrient levels. Examples of items included in food groups are presented in the Appendix. It is assumed that insects fed will be crickets or mealworms. As mealworms contain substantially more fat and energy than crickets, if an animal is overweight, a higher percentage of crickets to mealworms should be used.

Insects should be fed an appropriately fortified 8% calcium diet 24-48 hours prior to feeding them to the Callitrichids. The vegetables and starchy vegetables offered should be cooked (steamed or microwaved) to enhance digestibility. Nectar, if the animals consume nectar in the wild, can be fed (diluted 50:50 with water) and mixed with the diet. This is not in addition to the diet. Fruit must be decreased by weight as nectar is offered. If for logistic or cost reasons, it is felt that the use of insects should be decreased, increasing the nutritionally complete portion of the diet is appropriate (by weight).

Diet Example 1.

Food items	% in diet (by weight as fed)
Commercial marmoset diet*	72
Fruit	10
Vegetables	5
Starchy vegetables	5
Insects	8

*The commercial marmoset diet that will complement the diet above is one with the following specifications. This particular product is canned (hence the higher moisture content). With the use of this product, the diet must contain a source of vitamin C. (This can be obtained from the fruit, if a good source is used.) This product contains the following nutrients as stated on the label and/or in the informational literature:

Crude protein	minimum %	9.3	Ash	maximum %	2.5
Crude fat	minimum %	3.2	Calcium	minimum %	0.33
Crude fiber	maximum %	0.8	Phosphorus	minimum %	0.24
Moisture	maximum %	60	Vitamin D_3	IU/g	2.5

Diet Example 2.

Food items	% in diet (by weight as fed)
Commercial primate diet*	50
Fruit	12
Vegetables	10
Starchy vegetables	10
Insects	18

*The commercial primate diet that will complement the diet above is one with the following specifications. This product contains the following nutrients as stated on the label and/or in the informational literature:

Crude protein	minimum %	25	Ash	maximum %	6.1
Crude fat	minimum %	5	Calcium	minimum %	1.0
Crude fiber	maximum %	4	Phosphorus	minimum %	0.6
Moisture	maximum %	10	Vitamin D_3	IU/g	2.5

Diet Example 3.

Food items	% in diet (by weight as fed)
Commercial primate diet*[a]	47
Commercial marmoset diet*[b]	10
Water	3
Fruit	10
Vegetables	10
Starchy vegetables	10
Insects	10

*[a]The commercial primate diet which will complement the diet above is one with the following specifications. This product contains the following nutrients as stated on the label and/or in the informational literature:

Crude protein	minimum %	25	Ash	maximum %	6.1
Crude fat	minimum %	5	Calcium	minimum %	1.0
Crude fiber	maximum %	4	Phosphorus	minimum %	0.6
Moisture	maximum %	10	Vitamin D_3	IU/g	2.5

*[b] The commercial marmoset diet which will complement the diet above is one with the following specifications. This is a powdered product formulated to be mixed with water and heated to a gel. Thus water was added as part of the diet. It also is stated that it should be used with another manufactured primate diet (such as used in this example). This product contains the following nutrients as stated on the label and/or in the informational literature:

Crude protein	minimum %	33			
Crude fat	minimum %	14	Calcium	minimum %	0.85
Crude fiber	maximum %	6	Phosphorus	minimum %	0.67
Moisture	maximum %	2 or 0	Vitamin D_3	IU/g	2.5
Ash	maximum %	5			

Additionally, a diet including a dry manufactured extrusion plus a moistened mixture of powdered manufactured product and fruit has been fed successfully to cotton-top marmosets.[76]

The quantity of food to offer per day is difficult to determine unless based on accurate measurements of body mass (or body weight). Charting an animal's body mass and physical appearance over time will help identify optimal (and normal fluctuations) in weight. Deviations from normal can help identify impending problems, such as developing infectious disease. An average active adult Callitrichid will consume about 5% of its body weight per day, as dry matter. Total diet intake may approach 16 to 24% of body weight on an as fed basis (depending on the moisture content of the diet). However, amounts of food consumed also depend on exercise and physiological state. During lactation, intake may increase 1.5 times. If an animal is inactive, consumption may be less. In large colonies or where there is appreciable competition for food among animals of differing age, sex, or social dominance (or competing pests), sufficient food should be provided so small quantities remain after the feeding period. However, amounts of food offered should not be so large that sorting results in consumption of an imbalanced diet. Both the nutrient densities and digestibilities of the foods offered are important. The challenge for the animal care-giver is to assure that each animal meets its nutrient needs.

The quantities of foods in the above example diets to offer per day can be calculated by using the following formula:

Amount of a food item = (total amount of diet required per day)(% of food item in diet)/100

Food items should be of a size appropriate for easy handling by individual Callitrichids. Sizes and shapes can be varied for behavioral enrichment. Food sharing and stealing is common within family groups and may serve to teach the young about important food items. However, if fed as outlined above, problems of individuals in a group not receiving sufficient food because of competition should be minimized.

Certain foods (like excessive quantities of fruit) may periodically cause diarrhea in some animals. The manufacturer's literature for a gel diet states that loose stools may result from feeding large quantities. Reductions in the proportion of fruit or temporary restriction to a nutritionally complete primate biscuit or canned diet may clear up the problem. Use of a nutritionally complete primate diet is critical to proper dietary management of these animals, but the diet should be reassessed for nutrient content if one commercial product is substituted for another. Oral medications may be hand-fed in favorite food items.

Fresh water should be available at all times. Food and water dishes should be disinfected daily to prevent bacterial build-up, especially of *Pseudomonas* spp.

Feeding regimes for hand-rearing young are available from the studbook keeper and the Infant Diet/Care Notebook.[6] Zoos have hand-reared a number of Callitrichid infants successfully and reintroduced them after weaning to a family group for socialization and to learn parental care techniques.

Ultimately, it is the diet (food items) actually consumed that will determine nutrient status. If the diet (or certain portions of the diet) is not consumed, nutrient intakes may be inadequate. Thus, periodic assessment of diet consumption is important.

Following is an example method for determining diet consumption. Data on diet offered and consumed should be collected for at least five days. Different keepers should be involved to account for variations in food preparation. Consumption is calculated by determining the quantity (by weight) of food items offered and subtracting the quantity of food remaining. Food portions should be prepared by each care-giver, according to their normal procedures. Each item should be weighed on a digital scale before placing it in the food pan. Orts (leftover food) should be collected and weighed at the end of the feeding time or before the beginning of the next feeding time. Enrichment food items should be accounted for in the same manner.

Moisture concentrations of food may change from feeding to ort collection because of desiccation or from additions of water from rain or misting, and must be accounted for. Determinations of intake on a dry-matter basis can be made by using a drying oven to determine dry matter in samples of food items offered and of recovered orts. If a drying oven is not available, a food pan containing weighed food samples should be placed near, but outside, the cage where the animals are housed, in an area free of pests. The pan should be left for the same period of time as the fed diet and subjected to the same environmental conditions. The percentage water gain or loss should be determined and a correction factor calculated. This factor can then be used to determine the actual quantity of diet consumed without the conflicting problem of moisture change. A computer analysis (e.g., Zoo Diet

Analysisä or Zootritionä) can be used to calculate the nutrient content of the diet offered and consumed. For nutritional advice, please consult your nutritionist or obtain a name of a professional nutritionist from the AZA Nutrition Advisory Group.

Special Considerations

There are some issues affecting certain individuals or species of Callitrichids that deserve special consideration.

Overweight. If nutrient concentrations in the total diet are adequate, the amounts of each food item can be proportionately decreased (beginning with a 5% decrease) to reduce weight to normal. Other options include decreasing the proportion of calorically dense food items and/or increasing the proportion of lower calorie items. Body mass should be frequently monitored.

Seasonality. A common occurrence in the wild, animals in captivity occasionally undergo seasonal fluctuations in food intake and body mass. If these are determined to be normal for the species or an individual, adjustments in amounts of food offered can be made. Again, body mass should be frequently monitored.

Periodontal disease. Animals which consume primarily soft foods (that do not abrade dental tartar from teeth) have an increased susceptibility to periodontal disease. A nutritionally balanced diet also is important in maintaining oral health. Crunchy or hard foods should be offered periodically to help keep teeth clean.

Vitamin D. As previously discussed, it has been proposed that some Callitrichids may require more vitamin D than other New World primates.[5,72] The requirement for vitamin D for common marmosets has been stated to be 110 IU/day/100 g body weight (approximately equivalent to 22,000 IU/kg dietary DM), although the study conducted by these researchers was not designed to define the requirement.[72] If animals are housed indoors without UVB-light exposure, they must rely entirely on their diet to meet vitamin D needs; if outdoors, they can convert 7-dehydrocholesterol (a vitamin D precursor) in the skin to pre-vitamin D_3 upon exposure to sunlight. Research is underway with respect to vitamin D deficiency and vitamin D requirements for primates housed indoors;[44] 2,500 IU vitamin D_3/kg dietary DM is currently recommended.[51]

Wasting disease. Dietary protein and energy concentrations are very important in preventing protein/calorie malnutrition, which can lead to Marmoset Wasting Syndrome.[7] Research has shown that Callitrichids require about 150-160 kcal ME/BW_{kg}/day.[49] The NRC[51] estimated that 2.5-2.8 g of high-quality protein is required/BW_{kg}/day for adult Callitrichids.

Species specific concerns. Cotton-top tamarins have been used as a model for studying colitis and colon cancer. There may be a congenital or stress-related connection. There also have been reports of high blood pressure and heart disease in pygmy marmosets. The relationship to diet is unknown. Callimicos may be somewhat metabolically different from marmosets and tamarins and may handle certain nutrients such as vitamin D differently.[14] The animal manager should consult individual SSP manuals for details on species specific differences.

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Appendix

Food categories

These food categories and food items are representative of those that are available commercially. For additional information on food categories and exchanges of food items within a category, consult Zoo Menu Meddlerä (Brookfield Zoo), adapted from information published by the American Dietetic Association.[3]

Fruit	Vegetables	Starchy vegetables
apples	carrots	sweet potatoes
bananas	green beans	white potatoes
grapes	cucumbers	peas
oranges	green peppers	acorn squash
papayas	zucchinis	cooked rice
blueberries	cauliflower	cooked pasta
strawberries		corn
pineapple		cooked/canned navy beans
grapefruit		
pears		