in the last decade, numerous publications have been written with regard to the nutrition of giraffe and other ruminant browsers maintained in zoological institutions, inspired by several health problems suspected to have a nutritional origin. Thus, reports of rumen acidosis, chronic wasting, peracute mortality syndrome, energy maldistribution, hoof disease, inverse serum calcium and phosphorus levels, mortality caused by cold stress, overall poor body condition, urolithiasis, serous fat atrophy, chronic energy deficiency, dental disease, and pancreatic disease, among others, have been linked to nutritional imbalances in the giraffe diet.\textsuperscript{5,7,11,26,29} Traditional giraffe zoo diets in North America consist mainly of low-fiber pellets (ADF-16) and alfalfa hay, with the original pellets designed based on the domestic ruminant.\textsuperscript{29} Some zoos will occasionally add browse and some produce. This diet is high in soluble carbohydrates (sugars and starch) and low in total fiber. During the 1970s, and to cope with the peracute mortality syndrome reported in the giraffe, it was recommended to feed giraffes a diet containing low fiber and high protein (15\% to 18\% for adult nonlactating animals and 18\% to 20\% for calves and lactating cows). The idea of feeding zoo browsers, including giraffe, a low-fiber, high-protein pellet might be partly justified based on earlier studies that reported high levels of nitrogen in the rumen of free-ranging browsers when compared with grazers.

The claim that giraffes should have protein levels of 18\% dry matter (DM) in their diet is not supported by any direct studies.\textsuperscript{7} Traditional zoo commercial browser pelleted feeds such as ADF-16 are composed mainly of alfalfa meal, yellow corn grain, wheat middlings, and molasses. These pellets have the potential to supply high levels of readily fermentable carbohydrates (starch), increasing the availability of free glucose and stimulating the growth of certain ruminal bacteria, thereby increasing the production of volatile fatty acids and decreasing ruminal pH and cellulolytic bacteria. Studies with domestic sheep fed ADF-16 pellets, similar to the pellets used in giraffe diets, have shown sheep with a ruminal pH below 6 being maintained for more than 6 hours.\textsuperscript{19} Starch is negligible in the natural diets of wild browsers. Research has shown that giraffe fed a diet of low- and high-fiber pellets, plus alfalfa hay, will selectively ingest the pellets and alfalfa hay with higher levels of neutral detergent fiber (NDF) and acid detergent fiber (ADF) and lower levels of gross energy, contrary to the idea that giraffe as browsers (concentrate selectors), will select a low-fiber easily digestible diet.\textsuperscript{1} In 1973, for the first time, it was suggested that browsers such as the giraffe should be fed a diet higher in fiber and lower in protein.\textsuperscript{11} It took over 30 years for the zoo community to develop similar recommendations.\textsuperscript{26}

**NATURAL DIET OF THE GIRAFFE**

A thorough review of the giraffe natural diet has been given by Kearney.\textsuperscript{14} The giraffe is classified as a concentrate selector (browser) that in the wild consumes mainly foliage, including leaves and twigs of trees and shrubs, herbs and forbs, but these will vary with season and geographic location. The diet also includes wild fruits, flowers, bark, thorns, and seed pods.\textsuperscript{13} Giraffe in their natural environment will strip leaves from terminal shoots with their tongues or bite off the new nonlignified shoot ends, but in the dry season they may consume a significant proportion of lignified material. In the Serengeti, giraffe consume 50\% to 80\% of the available shoots of favored *Acacia* species, exerting a major impact on *Acacia* regeneration. Reports have indicated that giraffe will spend 53\% of the daylight hours searching for and consuming food, mainly
woody plants. *Acacia* spp. seem to be consumed the most, but as many as 66 different plant species may be consumed by giraffe in a year. Giraffe in their natural environment will consume little or no grass. Certainly, all the stimuli found in their natural habitat in the selection of browse and food are changed in zoo giraffe diets.

Despite the many in situ consumption and behavioral studies of giraffes, their nutrient requirements remain unknown.

**GIRAFFE: SPECIALIZED BROWSER OR SPECIALIZED GRAZER?**

The giraffe, being classified as a concentrate selector (browser), will have different dietary and possibly nutritional requirements than wild grazers. The giraffe, like kudu, moose, gerenuk, and okapi, are considered tree and bush foliage selectors. Browsers, considered early evolved ruminants, had to deal with an inefficient fiber digestion in the rumen because of short retention times. Browsers, in general, focus on cell contents, whereas grazers focus on cell wall constituents. As noted, giraffes in zoos have been offered diets high in soluble carbohydrates, low in fiber, and relatively high in protein. These diets originated from the time when wild herbivores were classified as grazers (grass and roughage eaters), concentrate selectors (browsers), and intermediate feeders. The latter might wrongly imply that browsers such as the giraffe are adapted to a diet high in soluble carbohydrates, with potential problems of producing rumen acidosis, as widely reported in domestic ruminants. Although the giraffe had been classified as a concentrate selector (browser), there have been studies suggesting that giraffes are not truly concentrate selectors. Giraffes have more omasal laminae, whereas most browsers have few and thick omasal laminae, with the omasum serving as a filter between the reticulum and abomasum for coarse particulate matter, plus having an absorptive surface function. Giraffes, like grazers, have rumens well connected to the abdominal wall and an advanced compartmentalization of the rumen, in contrast with other browsers. Furthermore, large ruminants require less energy per unit of volume of gastrointestinal tract, needing less energy-dense feeds than smaller ruminant-browsers.

Thus, the giraffe as a large ruminant might not fit the classification of a true concentrate selector, but rather an intermediate feeder or a facultative concentrate selector.

**RECENT RESEARCH**

**Serum Parameters**

There are not many studies comparing zoo and free-ranging giraffe but, in one study, serum parameters were compared between zoo and free-ranging giraffes. The results showed multiple differences in serum nutritional parameters between the two groups of giraffe. A total of 32 free-ranging giraffes and 20 zoo giraffes were used for the comparisons. Serum amino acid levels were higher in free-ranging animals, possible reflecting enhanced activity of the animals. Striking differences were found in the serum concentration of fatty acids. Free-ranging giraffes had higher concentrations of total omega-3 fatty acids because of elevations in α-linolenic, eicosatrienoic, eicosapentaenoic, and docosapentaenoic acids. Zoo animals, on the other hand, showed high levels of total omega-6 fatty acids, particularly linoleic and arachidonic acids due to their high levels in grains. The omega-3-to-omega-6 ratios were 0.48 ± 0.05 and 0.27 ± 0.07 for free-ranging and zoo giraffes, respectively, alerting the authors to recommend supplementation of omega-3 in the diet of zoo giraffes. In a more recent study, the addition of flax seed as a source of linolenic acid increased the serum omega-6 and omega-3 fatty acid levels, improving the omega-3-to-omega-6 ratios.

Serum cholesterol and saturated fatty acid levels have been seen to be higher in zoo giraffes, probably reflecting the composition of the dietary fatty acids. Serum retinol concentrations were significantly higher in zoo giraffes (89.3 µg/dl) when compared with free-ranging animals (24.1 µg/dl), although results reported in other studies showed less of a difference for retinol among these groups. Serum α-tocopherol values in zoo giraffes were low (4.43 µg/dl) when compared with free-ranging animals (41.89 µg/dl), although much higher levels of α-tocopherol (109 µg/dl) have been reported in zoo giraffes.

Inverse serum calcium-phosphorus ratios were found in 62% of giraffes in a study that measured mineral values in 24 animals at two institutions from samples collected over 9 years. Based on ISIS (International Species Information System) reports, captive adult giraffes in general show inverse calcium-phosphorus ratios. Mean serum calcium and phosphorus concentrations were 8.0 ± 0.8 mg/dl (n = 142) and 10.5 ± 2.9 mg/dl (n = 135), respectively. In a more recent publication, giraffes (n = 10) from five zoological institutions had higher serum calcium levels (8.6 to 10.6 mg/dl), lower serum phosphorus
levels (3.1 to 6.2 mg/dl), and normal serum calcium-phosphorus (Ca:P) ratios, ranging from 1.4 to 2.9. The serum phosphorus concentrations were much lower than those reported by ISIS. Two recent dietary studies of giraffes have shown positive effects on changing the serum calcium-phosphorus ratio after switching animals from a high-starch, low-fiber pellet (ADF-16) to a low-starch, high-fiber commercial pellet. In both studies, the serum calcium level was not affected by diet, but the serum phosphorus level was reduced by diet. Calcium homeostasis in vertebrates is precisely regulated, unlike phosphorus and magnesium. The serum phosphorus level was significantly reduced in one of the studies when changing from a high-starch, low-fiber to a low-starch, high-fiber diet that also reduced the level of phosphorus in the diet.

Physical Form of the Diet

A study has been performed comparing giraffes fed a regular zoo diet (R) consisting of a mix of commercial pelleted feeds (Mazuri Browser Breeder and Purina Omolene 200, in a 75:25 mix), ad lib alfalfa hay and fresh browse, when available, with giraffes fed a coarse, nonpelleted, experimental browser feed similar in form to a TMR (total mix ration) fed to dairy cows. The coarse diet (C) was also developed with the intention to reduce the dietary starch (from 14.2% to 1.5%) and increase the total nonfiber carbohydrates (from 9.6% to 15%). Giraffes were fed the diets for 21 days. The study found that giraffes fed the C diet slightly increased the amount of time engaged in feeding behavior, closer to that observed in wild giraffes. Increased eating time may increase salivary rumen buffering. Giraffes fed the C diet showed lower blood glucose levels (82.3 mg/dl) compared with the blood glucose levels (99 mg/dl) of R-fed giraffes. However, no major statistical differences were found with regard to total feed intake as percentage of body weight, total dry matter intake, serum blood urea nitrogen (BUN) level (16.6 versus 20.6 mg/dl, for R versus C diets), serum parameters, or digestibility coefficients among dietary treatments. Giraffes in both groups showed inverse calcium-to-phosphorus ratios. Studies such as the one described are important, but probably require more time for the animals to be exposed to the positive effects of reducing dietary soluble carbohydrates, such as starch, to see any significant animal changes (e.g., in serum values).

Digestibility and Feed Intake

Early studies on diet digestibility have shown that nutrients in the giraffe diet are used efficiently. For example, in diets in which the main ingredients in the pellets were corn grain, soybean meal, dehydrated alfalfa meal, corn cob, wheat middlings, and molasses, digestibility coefficients measured using the acid-insoluble ash technique for DM, crude protein (CP), NDF, ADF, and gross energy (GE) were 85.2%, 79.5%, 74.8%, 72.5%, and 82.6%, respectively. In other studies, different digestibility markers were tested in giraffe diets in which the main ingredients consisted of alfalfa hay, commercial pellets (Mazuri Browser Breeder) and beech (Fagus sylvatica) browse. In this study, the range of digestibility coefficients reported for DM, CP, NDF, and ADF were 63.5% to 74.3%, 73.4% to 82.4%, 49.9% to 62.2%, and 49.7% to 63.7%, respectively. In this study, the best digestibility markers were found to be acid-insoluble ash and alkalis (C36). Mean apparent digestibility of CP (59.7% to 82.4%), DM (52% to 85.2%), and NDF (32.5% to 74.8%) were reported for giraffes fed either a pelleted feed (Mazuri Browser Breeder and Purina Omolene 200, 75:25) and alfalfa hay or a coarse total mix diet plus alfalfa hay. The average dry matter intake for a group of two giraffes was 13.06 kg/day, representing 1.22% of the body weight of a traditional alfalfa hay and pellet diet (87.4% DM, 16.2% CP, 29.6% NDF, 183% ADF, 3.8% acid detergent lignin [ADL]). In other studies, average feed intake (percentage of body weight) for a group of six adult female giraffes were 1.2% (7.6 kg DM/day) and 1.25% (7.91 kg DM/day) for a traditional pellet-alfalfa hay diet (ADF = 23%; starch = 14.2%) and a coarse TMR diet (ADF = 26%; starch = 1.47%), respectively. One report on the DM intake of free-ranging giraffes showed males consuming at 1.6% of their body weight (BW) whereas females consumed at 2.1% of their BW.

Use of Woody Browse in Giraffe Feeding Programs

Browsers such as giraffes will benefit from the feeding of fresh woody browse that might provide nutrient supplementation or behavioral enrichment. Browse is particularly important for giraffes because giraffes are poor consumers of grass and alfalfa hay, even when offered ad lib, something that might contribute to the chronic energy deficit reported in some animals. The use of browse in giraffe and other antelope diets is considered
important in their feeding and health and a recommendation has been given to feed giraffe in zoos between 10% and 25% of their diet as woody browse. Browse may include trees, shrubs, woody vines, and stems. However, although important in the diet of giraffe and other browsers, woody browse is difficult to produce for most zoological institutions. Recently, browse farms have originated to supply this demand in some locations in North America. Carolina willow (Coastal plain willow, Salix caroliniana) and Australian acacia has been extensively used in some institutions in the feeding program of giraffe and other browsers. Willow browse (including leaves, twigs, bark) has a nutrient profile for giraffe as follows (%): DM, 47.1; CP, 8.5; ADF, 52.2; lignin, 20.2; cellulose, 32; starch, 1.57; Ca, 1.39; P, 0.17; Mg, 0.14; Na, 0.19; K, 0.87. In addition, willow browse has a Ca:P ratio of 8.2 and contains the following: (ppm) Cu, 6.7; Fe, 44.4; Mn, 14.6; Mo, 9.6; and Zn, 114.4. Its GE (kcal/g) = 4.8. The calculated digestibility of the willow browse for giraffe based on in vitro studies is 25.9%. Willow has been ensiled for the purpose of prolonging the browse season and research is underway to determine the acceptability of silage for giraffes and other browsers, as previously done for black rhinoceroses (willow, hazel, and maple silage). A practical way to estimate edible browse has been reported by equations based on branch weight and weight of the leaves, with the branch diameter at the point of cutting.

**Water Intake**

Giraffes may obtain all their water needs from the food they consume, given adequate moisture content, and will drink regularly if available. In the Namib desert, giraffes were rarely seen drinking until the installation of artificial watering holes, at which giraffes have been observed drinking regularly, sometimes on consecutive days. Water intake is dependent on the amount of water consumed in the diet, dry matter intake, ambient temperature, dietary salt, and precipitation. It is difficult to estimate the amount of water consumed by giraffes daily and therefore should be available at all times.

**NUTRIENT RECOMMENDATIONS**

Although the nutrient requirements of giraffe are unknown, new recommendations have been given based on the historical medical records of zoological institutions in North America and elsewhere. The new recommendations have stimulated the feed industry to start producing feeds that include new ingredients in their pellets, such as aspen, soybean hulls, oat hulls, and beet pulp, to reduce the starch content to less than 5% and to increase the ADF to more than 30% in giraffe and other browser feeds. The new nutrient recommendations (Table 79-1) are different from those given in the Giraffe Husbandry Resource Manual of the Association of Zoos and Aquariums, Antelope and Giraffe Taxon Advisory Group, and from the NAG (Nutrition Advisory Group, AZA), but in general agree with the European recommendations.

Based on health conditions discussed earlier, nutrition recommendations have evolved to try to improve the nutritional health of giraffes without being based on nutrition research studies to establish nutrient requirements. Since initial recommendations were provided in 1997, dietary CP concentrations have decreased because of the realization that high crude protein diets may exacerbate rumen acidosis. Additionally, with the inverse Ca:P ratio observed in some giraffe populations, recommended dietary calcium concentrations have narrowed, with a relative increase, and phosphorus concentrations have decreased.

**PRACTICAL DIETS**

Given the expected growth of giraffes (Fig. 79-1), three age-related diets may be developed for the juvenile (<12 months), the subadult (13 to 24 months) and adult (>24 months; Table 79-2). The maintenance energy requirements of giraffes have been calculated using a range of 107.6 to 143 multiplied by the metabolic weight BW kg. This is very similar to the estimate presented by Robbins (141.4 x BW [kg]0.75), essentially twice the basal metabolic rate.

A typical diet may be prepared to include a low-starch complete feed (loose or pelleted) and hay (legume or legume-grass mixture), with the complete feed offered at 50% to 75% of the required calories and the hay offered at 25% to 50% of the daily caloric requirement. Woody browse should be offered daily to elicit appropriate behaviors and prevent stereotypies (see earlier). The quantity of browse offered should not exceed that which reduces the consumption of the complete feed. Produce may be offered for training and enrichment, but should include items that are low in starch and calories such as lettuce, green beans, and carrots.

In colder weather, energy requirements may increase by 24% (175 x BW [kg]0.75), with a subsequent need to increase dietary calories. One of the concerns with giraffes is their inability to consume adequate amounts
<table>
<thead>
<tr>
<th>Nutrient, DM Basis</th>
<th>1997&lt;sup&gt;b&lt;/sup&gt;</th>
<th>2005&lt;sup&gt;c&lt;/sup&gt;</th>
<th>2006&lt;sup&gt;d&lt;/sup&gt;</th>
<th>2009&lt;sup&gt;e&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP (%)</td>
<td>17.8-22.2</td>
<td>10-14</td>
<td>14</td>
<td>&gt;14</td>
</tr>
<tr>
<td>ADF (%)</td>
<td>NR*</td>
<td>25-30</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>NDF (%)</td>
<td>NR</td>
<td>NR</td>
<td>35-50</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>NR</td>
<td>2-5</td>
<td>NR</td>
<td>4-8</td>
</tr>
<tr>
<td>Starch (%)</td>
<td>NR</td>
<td>&lt;10</td>
<td>NR</td>
<td>7-10</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>0.16-0.82</td>
<td>0.65-1.0</td>
<td>0.70-0.97</td>
<td>0.8</td>
</tr>
<tr>
<td>P (%)</td>
<td>0.11-0.49</td>
<td>0.35-0.5</td>
<td>0.36-0.40</td>
<td>0.3</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>0.1-0.2</td>
<td>&gt;0.3</td>
<td>0.18-0.24</td>
<td>0.3</td>
</tr>
<tr>
<td>Na (%)</td>
<td>0.06-0.18</td>
<td>NR</td>
<td>0.10-0.44</td>
<td>0.1</td>
</tr>
<tr>
<td>K (%)</td>
<td>0.5-0.89</td>
<td>NR</td>
<td>1.6-1.8</td>
<td>NR</td>
</tr>
<tr>
<td>Cu (ppm)</td>
<td>6.7-10.0</td>
<td>10-15</td>
<td>10-12</td>
<td>10-15</td>
</tr>
<tr>
<td>Fe (ppm)</td>
<td>30-50</td>
<td>NR</td>
<td>126-139</td>
<td>NR</td>
</tr>
<tr>
<td>I (ppm)</td>
<td>0.1-0.8</td>
<td>NR</td>
<td>0.3-0.4</td>
<td>NR</td>
</tr>
<tr>
<td>Mn (ppm)</td>
<td>20-40</td>
<td>NR</td>
<td>54-57</td>
<td>NR</td>
</tr>
<tr>
<td>Se (ppm)</td>
<td>0.08-0.20</td>
<td>NR</td>
<td>0.12-0.18</td>
<td>NR</td>
</tr>
<tr>
<td>Zn (ppm)</td>
<td>11-33</td>
<td>NR</td>
<td>54-68</td>
<td>NR</td>
</tr>
<tr>
<td>Vitamin A (IU/kg)</td>
<td>1111-3889</td>
<td>3900</td>
<td>1500-2200</td>
<td>5000-6000</td>
</tr>
<tr>
<td>Vitamin D3 (IU/kg)</td>
<td>556-1111</td>
<td>750</td>
<td>400-500</td>
<td>1200</td>
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<tr>
<td>Vitamin E (IU/kg)</td>
<td>133-389</td>
<td>60</td>
<td>120-178</td>
<td>100-150</td>
</tr>
</tbody>
</table>

NR, No recommendation provided.
of food when their energy requirements increase. To compensate for the increased dietary requirements, dietary items that are more calorically dense need to be offered during periods of high energy needs to ensure adequate energy balance. In the example given in Table 79-2, if dietary energy increases 24%, the complete feed needs to have a 35% increase in caloric density to prevent the need for the animal to increase its daily dry matter intake.

Acknowledgment

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REFERENCES