BRIEF REPORTS

Consumption of Cyanogenic Bamboo by a Newly Discovered Species of Bamboo Lemur

KENNETH E. GLANDER¹, PATRICIA C. WRIGHT², DAVID S. SEIGLER³, VOARA RANDRIANASOLO⁴, AND BODOVOLOLONA RANDRIANASOLO⁴.

^{1,2}Department of Biological Anthropology and Anatomy, Duke University, Durham, North Carolina; ² Department of Biology, California Institute of Technology, Pasadena;

³Department of Plant Biology, University of Illinois, Urbana; ⁴Parc Botanique et Zoologique de Tsimbazaza, Antananarivo, Democratic Republic of Madagascar

Three species of bamboo-eating lemurs were found to be sympatric in the southeastern rain forests of Madagascar. Sympatric species generally differ in habitat utilization or diet, but these three closely related bamboo lemurs lived in the same habitat and all ate bamboo. Behavioral observation revealed that they did select different parts of the bamboo, and chemical analyses confirmed that there was a difference in the secondary compound content present in those selections. The growing tips of *Cephalostachyum* cf *viguieri* selected by the golden bamboo lemur (*Hapalemur aureus*) contained 15 mg of cyanide per 100 g fresh weight bamboo while the leaves of *C. perrieri* selected by the gentle bamboo lemur (*H. griseus*) and the mature culms of *C. cf viguieri* selected by the greater bamboo lemur (*H. simus*) did not contain cyanide. Since each individual golden bamboo lemur ate about 500 g of bamboo per day, they daily ingested about 12 times the lethal dose of cyanide. The mechanism by which this small primate avoids the acute and chronic symptoms of cyanide poisoning is unknown.

Key words: *Hapalemur aureus*, *Hapalemur griseus*, *Hapalemur simus*, cyanide, diet, niche separation

INTRODUCTION

In 1986, while studying the gentle bamboo lemur (*Hapalemur griseus*) in the Ranomafana National Park, Madagascar, Wright and colleagues [Wright et al., 1987; Meier et al., 1987] discovered a new species of bamboo lemur (*H. aureus*, or golden bamboo lemur) and found another species that had not been seen since the early 1970s (*H. simus*, or greater bamboo lemur). All three of these lemurs live in the same habitat and all three eat bamboo, in the case of the golden and greater bamboo lemur, the same species of bamboo [Wright et al., 1987]. Here we report the preliminary results of an ongoing behavioral and ecological study of these three bamboo-eating lemurs.

Received for publication February 6, 1989; revision accepted August 2, 1989.

Address reprint requests to K.E. Glander, Department of Biological Anthropology and Anatomy, Wheeler Building, 3705B Erwin Rd., Duke University, Durham, NC 27705.

© 1989 Alan R. Liss, Inc.

MATERIALS AND METHODS

Observation

Golden bamboo lemurs were observed for a total of 153 hours during June–August 1986; June–November 1987; and June–November 1988. Marked individuals were followed for as long as they could be kept in sight. Activities were recorded, and if the activity was feeding, the part of the plant eaten was noted.

Collection of Weights

Capture of *H. griseus* and *H. aureus* individuals was accomplished in May 1988 using the Pneu-dart system (Pneu-Dart Inc., HC 31, Williamsport, PA 17701). This system employs disposable non-barbed darts with a 3/8-inch needle delivered by a carbon dioxide powered gun. The darts were loaded with 0.4 cc (40 mg) of Ketalar (Ketamine hydrochloride, 100 mg/ml) (Bristol Laboratories, Syracuse, NY 13201).

Collection of Plant Material

Samples of two species of bamboo, *Cephalostachyum cf. viguieri* and *Cephalostachyum perrieri*, were collected and tested in May 1987; May, June, and December 1988; and May 1989. The four parts of each plant collected were the leaf, new shoot, young stem pith, and trunk. Collections were made at the exact location where individuals were feeding or the material dropped was collected in an effort to obtain plant material as similar as possible to what the animals ate.

The bamboo genus *Cephalostachyum* occurs in Indomalaysia and Madagascar [Airy Shaw, 1973]. Both *Cephalostachyum* species in this study are native to this area of Madagascar and there are at least 10 species of bamboo in the park area (Edelman personal communication). This group of grasses is poorly known and the systematic status of these two species and the genus *Cephalostachyum* is unclear. Thus the identification of the bamboo in this paper as *C. viguieri* must be considered provisional.

Chemical Analyses

The presence or absence of cyanide was determined by the Feigl Anger test [Feigl & Anger, 1966; Tantisewie et al., 1969]. All analyses were started and completed in the shade, at the same temperature and humidity. All tests were done in the field in May 1987; May, June, and December 1988; and May 1989. The plant parts tested were chopped into 1-cm-long bits and added to glass test tubes. The material was macerated in the bottom of vials before a strip of filter paper impregnated with Feigl Anger solution [Feigl & Anger, 1966] was added and a cork placed in the top of the vials. Care was taken so that the paper did not touch the plant material. The white strip changed to blue in the presence of cyanide. The color of the test strips was noted at intervals of 15, 30, 60, and 240 minutes. Replicates (a minimum of 3–4 from each plant) of leaves, young stems, and mature stems of each species were examined.

To determine the amount of cyanide present, the outer fibrous material of the bamboo was removed from approximately the last foot of growth collected on May 20, 1987. The white tender inner material (115 g) was cut into small pieces as quickly as possible and added to the hot alcoholic extraction medium (Saint Claude, Rhum de Luxe, Extra Fin, Special 43°, Carte Noire). The mixture was boiled for 10 minutes, cooled, and decanted. After boiling, the residual plant material still contained residual cyanogenic materials as indicated by tests with Feigl Anger paper [Tantisewie et al., 1969; Feigl & Anger, 1966]. This material was reboiled with 200 ml water for an additional 10 minutes. It still gave positive tests

for cyanide, and it is clear that the extraction under field conditions was inefficient. The percent of cyanide was later determined in the laboratory.

Cyanogenic compounds in the extract were decomposed by addition of emulsin (Sigma, St. Louis, MO) and the resulting cyanide was captured in 0.1 N sodium hydroxide solution in Warburg flasks. The basic solution was removed and cyanide content determined by colorimetric analysis [Lambert et al., 1975]. Each sample was repeated four times. A control was run on the extraction medium (Rhum de Luxe).

RESULTS

Feeding

At least five species of bamboo are common at the research site. One of these, *C. cf viguieri*, was the principal food of golden bamboo lemurs and the only bamboo species they were observed to eat. They ate shoots, leaf bases, pith, and the viny part of this bamboo. Greater bamboo lemurs ate the mature culms (stalks) of the same bamboo species while gentle bamboo lemurs ate the leaf bases and blades of a related species of bamboo, *C. perrieri*.

Ninety-one percent of the golden bamboo lemurs' feeding minutes were spent eating bamboo, while the remainder was spent feeding on one unknown palm fruit and one unknown *Melastoma* fruit. Feeding began shortly after dawn (0530) and continued for an average of 30 minutes ($n = 45$, range 20–50). These feeding bouts were followed by rest periods of 30 to 40 minutes, which were followed by another feeding bout and rest period. Feeding and resting alternated until an extended rest period began at 1000 and lasted until 1500. After 1500, feeding and resting periods continued to alternate until dark at 1745.

From June to August, bamboo shoots are rare and the golden bamboo lemurs spent 60% of their feeding time eating leaf bases and the inside of the viny part of *C. cf viguieri*. By December, new shoots of *C. cf viguieri* were again common, and the golden bamboo lemurs spent 75% of their feeding time eating shoots with the remainder spent eating bamboo leaf bases and the pith from the viny part of *C. cf viguieri* as well as the palm and *Melastoma* fruit.

The shoots, leaf bases, and pith of *C. cf viguieri* all contained cyanide, with the pith containing high levels. Each of the more than 200 samples tested turned the test paper dark blue within the first 30 seconds. Leaf blades and culms of *C. cf viguieri* tested negative for cyanide as did all plant parts of *C. perrieri*. Testing at various times during a three-year period (see Collection of Plant Material) indicated no seasonal variation in the production of cyanide.

The cyanide content of the extracted sample was 15 mg HCN per 100 g fresh weight. The extraction medium (Rhum de Luxe) contained no cyanide.

Body Weight

The only wild-caught *H. griseus* weighed 770 g, whereas the average weight of five captive *H. griseus* at the Duke Primate Center was 936 g (Table I). The average weight of three *H. aureus* captured during May 1987 was 1,560 g (Table I). One of the adult males was captured again in October 1988 and had gained 120 g. The only weight for adult *H. simus* is 2,365 g for one adult male [Meier et al., 1987].

DISCUSSION

Plants that release more than 10–20 mg HCN per 100 g of fresh plant tissue are considered potentially dangerous to livestock [Moran, 1954; Kingsbury, 1964]. Therefore, the amount of cyanide (15 mg/100 g fresh weight) found in the soft

TABLE I. Lemur weights

Species	Sex	Weight (g)
<i>Hapalemur aureus</i>	F	1,500
<i>H. aureus</i>	M	1,640
<i>H. griseus</i>	M	770
<i>H. griseus</i> ^a	M	1,226
<i>H. griseus</i> ^a	M	941
<i>H. griseus</i> ^a	M	1,022
<i>H. griseus</i> ^a	F	1,167
<i>H. aureus</i> ^b	M	1,540
<i>H. aureus</i> ^b	M	1,660

^aCaptive animals held at the Duke Primate Center.^bSame individual captured in May and October 1988.

stems and growing tips of *C. cf. viguieri* would be dangerous to most mammals, but was not harmful to the golden bamboo lemurs.

Free hydrogen cyanide is readily absorbed by most animals and is highly toxic [Poulton, 1983]. An oral lethal dose of HCN for the mouse is 3.7 mg/kg; dog, 4.0 mg/kg; cat, 2.0 mg/kg; rat, 10 mg/kg [Christensen & Fairchild, 1976]. The lethal dose for sheep is 2.0 mg/kg body weight [Harborne, 1982]. The oral lethal dose of hydrogen cyanide for humans is 0.5–3.5 mg/kg body weight or about 50–250 mg for a typical adult human [Montgomery, 1969; Christensen & Fairchild, 1976].

Assuming that an adult golden bamboo lemur (1.5 kg) is proportionately as sensitive to cyanide as the animals above, an average (excluding humans) lethal dose of 6.5 mg would be found in 43 g of bamboo eaten. The golden bamboo lemurs ate about 500 g of bamboo per day, or about 12 times the lethal dosage of cyanide daily. This undoubtedly represents a low estimate because of the inefficiency of the field extraction method. Much larger amounts of cyanide (90–800 mg HCN per 100 g fresh weight) have been reported from other bamboo species [Schwarzmaier, 1977; Bagchi & Ganguli, 1943].

We do not know how golden bamboo lemurs avoid cyanide poisoning, but there are several possibilities. For most animals, the major mechanism of cyanide detoxification involves conversion of cyanide to thiocyanate [Montgomery, 1979]. This process requires the enzyme rhodanese, which is present in most animal tissues, plus amino acids such as methionine or cysteine to convert cyanide to thiocyanate. Based on nutritional data for other bamboo species, sulfur-containing amino acids are relatively low [Schaller et al., 1985]. Thus, this method of detoxification seems unlikely for the golden bamboo lemur.

Another method of detoxification is to keep the stomach acidic, since the release of cyanide is inhibited by low pH. For humans and other monogastric animals, acidic stomach conditions prevent the formation of cyanide. Both the greater bamboo lemur (which eats mature culms) and the gentle bamboo lemur (which eats leaf bases) have unspecialized stomachs [Hill, 1953] and short, globular ceca that lack apical narrowing and are the simplest of all the lemurs [Tattersall, 1982]. This simplicity in their stomachs and ceca is surprising given their extremely fibrous diet, but resembles the digestive system of the panda [Schaller et al., 1985]. The digestive system of the golden bamboo lemur is unstudied.

Bamboo is a plentiful resource, but relatively few mammals and certainly no other prosimians utilize it for food. Probably the best-known herbivore that feeds almost exclusively on bamboo is the giant panda (*Ailuropoda melanoleuca*)

[Schaller et al., 1985]. During some portions of the year, the giant panda eats shoots of the genus *Fargesia* as an exclusive food, but not those of the genus *Sinarundinaria*, which is common in the same area [Schaller et al., 1985]. These shoots have considerable total fiber (76–90%) and are low in nutrients, especially the sulfur-containing amino acid methionine [Schaller et al., 1985; Dierenfeld et al., 1982; Dierenfeld, 1981], but apparently were not tested for cyanide.

Other mammals utilizing this abundant food resource are two Southeast Asian rodents (*Hapalomys longicaudatus* and *Rhizomys sinense*), a South American rat (*Dactylomys dactylinus*), and African monkey (*Cercopithecus mitus kanditi*), and a South American monkey (*Callicebus moloch*) [Emmons, 1981; Schaller et al., 1985; Wright, 1985].

The gentle bamboo lemur (*H. griseus*) can be found throughout most of the eastern rain forest, but the golden bamboo lemur (*H. aureus*) is among the rarest primates of Madagascar and only found in the southeastern rainforest. Golden bamboo lemurs' geographical distribution is closely linked to that of bamboo and may be limited to those areas of Madagascar where cyanogenic bamboo occurs.

The panda-like bamboo lemurs have exploited an open niche and appear to have specialized to the extent of dividing up the niche based on the chemical and nutrient content of the bamboo. Niche partitioning at this level may be more common among primates than has been formerly appreciated. Ganzhorn [1988] suggested that food selection based on primary and secondary plant chemicals is an important factor in the mechanisms permitting several primate species to be sympatric. Additional studies of the three bamboo-eating lemurs of Madagascar are presently underway to further define this dynamic plant-primate interaction.

CONCLUSIONS

- 1) Three species of bamboo-eating lemurs are sympatric in the rain forests of Madagascar.
- 2) These three species of lemurs utilize the same habitat, and all eat bamboo as a principal component of their diet.
- 3) The three species select different parts of the bamboo.
- 4) The diet of the golden bamboo lemur contained at least 15 mg of cyanide per 100 grams of fresh weight bamboo.
- 5) Based on a daily diet of 500 g of bamboo, the golden bamboo lemur ingested about 12 times the lethal dose of cyanide each day.
- 6) The mechanism by which the golden bamboo lemurs avoid cyanide poisoning is unknown.

ACKNOWLEDGMENTS

This study was supported by the Sub-Saharan African Cooperative Science Program of the National Science Foundation (NSF INT-8602286), Wildlife Conservation International, World Wildlife Fund-US Primate Program, Duke University Research Council, National Geographic Society, Chicago Zoological Society, and the Dourocouli Foundation. We thank the Ministère de la Production Animale (Elevage et Pêche) et des Eaux et Forêts, Department of Water and Forests of Madagascar, and the Missouri Botanical Garden for their cooperation and help. Thanks to George Schatz, Porter Lowry II, Roan McNab, Anita Brinker, David Meyers, Patrick Daniels, Joe Macedonia, and our guides, Emile Rajery, Loret Rasabo, and Pierre Talata of Ambatolahy without whose assistance the successful completion of this study would have been difficult. Our special thanks to Tom Soderstrom, David Edelman, and Emmet Judziewicz for identifying the bamboo. This is paper no. 448 from the Duke University Primate Center.

REFERENCES

- Airy Shaw, H.K. WILLIS FLOWERING PLANTS AND FERNS, 8th ed. Cambridge, Cambridge University Press, 1973.
- Bagchi, K.N.; Ganguli, H.D. Toxicology of young shoots of common bamboos (*Bambusa arundinacea* willd.). THE INDIAN MEDICAL GAZETTE 78:40-42, 1943.
- Christensen, H.E.; Fairchild, E.J. Registry of toxic effects of chemical substances. Natl. Inst. Occup. Safety Health, U. S. Public Health Serv., Rockville, Maryland. HEW PUBLICATION NIOSH, pp. 76-191, 1976.
- Dierenfeld, E. THE NUTRITIONAL COMPOSITION OF BAMBOO AND ITS UTILIZATION BY THE GIANT PANDA. M. S. Thesis, Cornell University, Ithaca, New York, 1981.
- Dierenfeld, E.S.; Hintz, H.F.; Robertson, J.B.; Van Soest, P.J.; Oftedal, O.T. Utilization of bamboo by the giant panda. JOURNAL OF NUTRITION 112(4):636-641, 1982.
- Emmons, L.H. Morphological, ecological, and behavioral adaptations for arboreal browsing in *Dactylomys dactylinus* (Rodentia, Echimyidae). JOURNAL OF MAMMALOGY 62:183-189, 1981.
- Feigl, F.; Anger, V. Replacement of benzidine by copper ethylacetoacetate and tetra base as spot-test reagent for hydrogen cyanide and cyanogen. ANALYST 91: 282-284, 1966.
- Ganzhorn, J.U. Food partitioning among Malagasy primates. OECOLOGIA, 75: 436-450, 1988.
- Harborne, J.B. INTRODUCTION TO ECOLOGICAL BIOCHEMISTRY. New York, Academic Press, 1982.
- Hill, W.C.O. PRIMATES: COMPARATIVE ANATOMY AND TAXONOMY. London, Edinburgh University Press, 1953.
- Kingsbury, J.M. POISONOUS PLANTS OF THE UNITED STATES AND CANADA. Englewood Cliffs, N.J., Prentice-Hall, 1964.
- Lambert, J.L.; Ramasamy, J.; Paukstelis, J.V. Stable reagents for the colorimetric determination of cyanide by modified König reactions. ANALYTICAL CHEMISTRY 47:916-918, 1975.
- Meier, B.; Albignac, R.; Peyrieras, A.; Rimpler, Y.; Wright, P. A new species of *Haplemur* (primates) from South East Madagascar. FOLIA PRIMATOLOGICA 48:211-215, 1987.
- Montgomery, R.D. Cyanogens. Pp. 143-157 in TOXIC CONSTITUENTS OF PLANT FOODSTUFFS. I. E. Liener, ed. New York, Academic Press, 1969.
- Montgomery, R.D. Cyanogenetic glucosides. Pp. 515-527 in INTOXICATIONS OF THE NERVOUS SYSTEM. P.J. Vinken, G.W. Bruyn, eds. New York, North-Holland Publishing Co., 1979.
- Moran, E.A. Cyanogenetic compounds in plants and their significance in animal industry. AMERICAN JOURNAL OF VETERINARY RESEARCH 15:171-175, 1954.
- Poulton, J.E. Cyanogenic compounds in plants and their toxic effects. Pp. 117-157 in HANDBOOK OF NATURAL TOXINS. Vol. 1: PLANT AND FUNGAL TOXINS. R.F. Keeler, A.T. Tu, eds. New York, Marcel Dekker, 1983.
- Schaller, G.; Jinchu, H.; Wenshi, P.; Jing, Z. GIANT PANDAS OF WOLONG. Chicago, University of Chicago Press, 1985.
- Schwarzmaier, U. Cyanogenesis of *Dendrocalamus/Taxiphyllin*. PHYTOCHEMISTRY 16:1599-1600, 1977.
- Tantisewie, B.; Ruijgrok, H.W.L.; Hegnauer, R. Die Verbreitung der Blausäure bei den Cormophyten. 5. Mitteilung: Über cyanogene Verbindungen bei den Parietales und bei einigen weiteren Sippen. PHARMACEUTISCH WEEKBLAD 104:1341-1355, 1969.
- Tattersall, I. THE PRIMATES OF MADAGASCAR. New York, Columbia University Press, 1982.
- Wright, P.C. THE COSTS AND BENEFITS OF NOCTURNALITY FOR *AOTUS TRIVIRGATUS* (THE NIGHT MONKEY). Ph.D. thesis, City University of New York, 1985.
- Wright, P.C.; Daniels, P.S.; Meyers, D.M.; Overdorff, D.J.; Rabesoa, J.A. Census and study of *Haplemur* and *Propithecus* in Southeastern Madagascar. PRIMATE CONSERVATION 8:84-88, 1987.