**American Journal of Primatology 68:143–151 (2006)**

RESEARCH ARTICLE

# Nutritional Significance of the Selective Ingestion of *Albizia zygia* Gum Exudate by Wild Chimpanzees in Bossou, Guinea

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The selective ingestion of plant gum exudates by chimpanzees has been frequently observed at various study sites. At Bossou, Guinea, chimpanzees also frequently ingest *Albizia zygia* gum exudate. A functional explanation for this behavior is lacking, so we evaluated its possible contribution of energy in the form of short-chain fatty acids (SCFA) as well as minerals. An in vitro fermentation study of *A. zygia* gum using the fecal bacteria of a Bossou chimpanzee showed that carboxylic acids were produced with a 6-hr lag phase up to 44 mmol/l by 18 hr of incubation. Acetate was the most abundant acid produced, followed by lactate and propionate. The energy supplied from the fermentation of a piece of gum exudate (20–30 g) was negligible in comparison with the estimated daily energy requirements of chimpanzees in the wild. However, *A. zygia* gum exudate (20–30 g) can supply sufficient amounts of calcium, manganese, magnesium, and potassium to fulfill the daily requirements for these minerals in chimpanzees. Am. J. Primatol. 68:143–151, 2006.


**Key words: wild chimpanzees; selective ingestion of *Albizia zygia* gum; intestinal fermentation; mineral supply**

## INTRODUCTION

Members of the family Mimosaceae, such as *Acacia* spp., produce gum exudates, which have been used by the food industry for emulsification, coating, encapsulation, and gum candies. *Acacia* gum has a high molecular weight of

Contract grant sponsor: HOPE Project, Japan Society for Promoting Science and the Ministry of Education, Culture, Sports, Science, and Technology, Japan (Grant-in-Aid for Young Scientists No. 02628).

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Received 15 December 2004; revised 19 April 2005; revision accepted 20 April 2005

DOI 10.1002/ajp.20212
Published online in Wiley InterScience (www.interscience.wiley.com).

acidic heteropolysaccharide, which is composed mainly of arabinogalactan with rhamnose and gluculonic acid. Since *Acacia* gum can reach the large intestine without being digested in the small intestine, it is categorized as a nondigestible carbohydrate or dietary fiber. It is fermented by intestinal bacteria to short-chain fatty acids (SCFA), specifically propionic acid, in the large intestine [Adiotomre et al., 1990; Annison et al., 1994; May et al., 1994]. It is also known as a bifidogenic dietary fiber [Michel et al., 1998]. Because of its physical properties, it retards glucose absorption, increases stool mass, and traps bile acids. Because of these effects, *Acacia* gum has the potential to beneficially modify the physiological status of humans [Adiotomre et al., 1990]. *Acacia* gum is traditionally utilized by African and Indian populations to improve intestinal transit and digestive comfort [Cherbut et al., 2003].

*Albizia* spp. is also capable of producing exudates that are similar to those produced by *Acacia* spp. because it belongs to the same subfamily [Allen & Allen, 1981]. It may have biological effects similar to those of *Acacia* gum. However, *Albizia* gum is not recommended for human consumption because it has a high content of aluminum and heavy metals [Anderson & Morrison, 1990]. The selective ingestion of plant gum exudate from *Albizia* spp. by wild chimpanzees has been frequently observed in various locations [Nishida & Uehara, 1983; Sugiyama & Koman, 1987, 1992; Yamakoshi, 1998]. In one instance (Ohashi, unpublished observation), Bossou chimpanzees chose to consume the plant gum exudate. In fact, they hastened up a tree when they found the gum on the stem and branches (Fig. 1A and B). These observations suggest that there may be some nutritional reasons behind the selective gum ingestion.

Earlier studies suggested the importance of gum-feeding for small insectivorous primates, such as Callitrichidae [Coimbra-Filho & Mittermeier, 1977; Garber, 1984]. Garber [1984] stressed the importance of *Anacardium exelsum* and *Spondias mombin* in supplying calcium (Ca) to pregnant and lactating females. More recently, Heymann and Smith [1999] suggested the importance of gum-feeding in the captive management of tamarin monkeys based on their feeding ecology. The importance of plant gum exudates as a special source of Ca for small insectivorous primates has been established. However, such feeding habits in wild chimpanzees have not yet been elucidated. In this study, we examined *A. zygia* gum in terms of its fermentability in the large intestine of wild chimpanzees, and its cation composition in order to better elucidate this phenomenon.

## MATERIALS AND METHODS

Field research was conducted in the forests surrounding Bossou village, Lola Prefecture, Republic of Guinea, West Africa. We collected the fresh gum exudate of *Albizia* spp. to analyze the cation concentration and conduct in vitro fermentation. Of the *Albizia* spp. specimens available in the forest around Bossou, the gum exudate of *A. zygia* was the most plentiful. Accordingly, the gum exudate of *A. zygia* was used for further studies.

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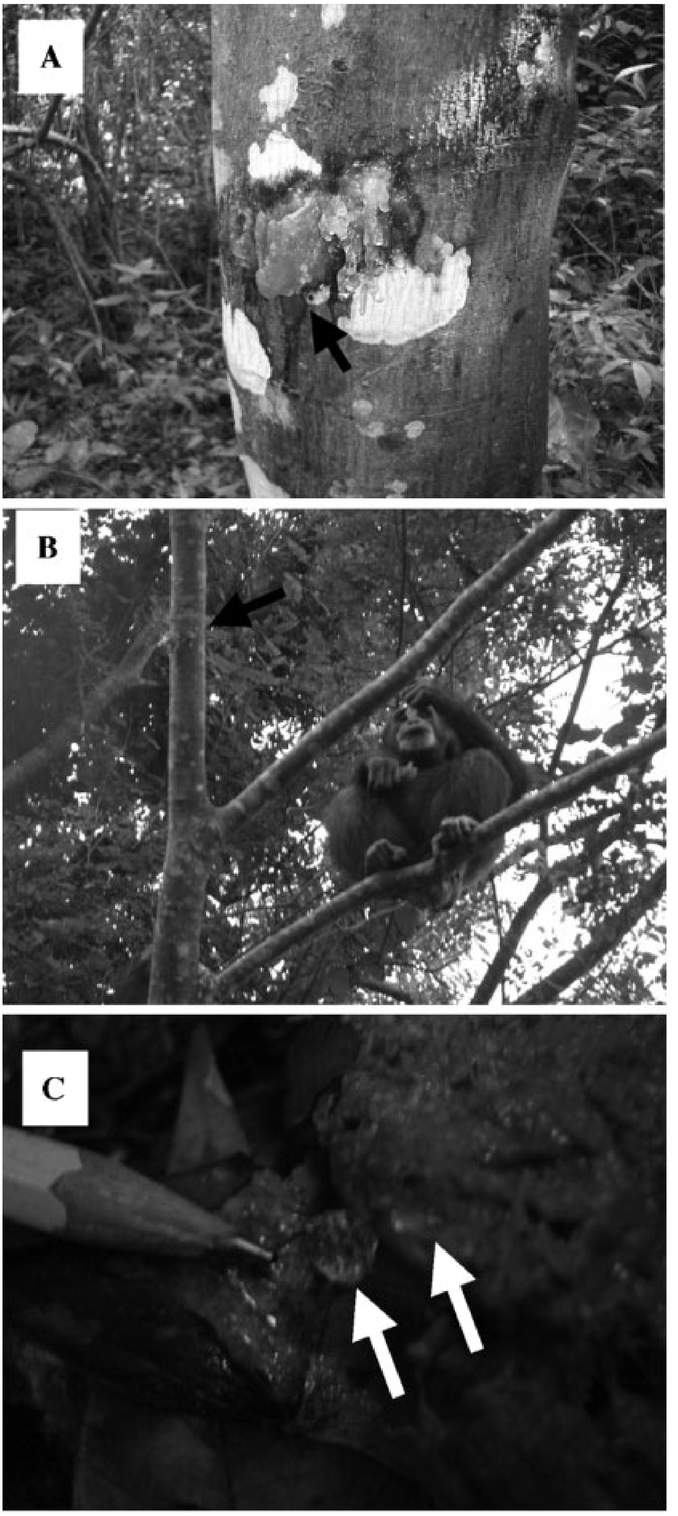
Fig. 1. Typical gum exudates of an *Albizia zygia* tree (arrow). **A:** An exudate weighing ca. 30 g. The figure shows a female chimpanzee eating *A. zygia* gum. She took pieces of gum in both hands. The arrow indicates gum exudate on the stem (**B**). Residual gum in the feces of a female chimpanzee that had consumed *A. zygia* gum the day before is shown. The arrows denote the presence of small pieces of gum (**C**).


A
B
C

### In Vitro Fermentation of *A. zygia* Gum by the Fecal Bacteria of a Wild Chimpanzee

Portions (0.1 g) of the freshly collected *A. zygia* gum were put into 2-ml screw-capped plastic tubes. The feces ($\sim$10 g) from a female adult chimpanzee (Vélu, 45 years old) that had consumed *A. zygia* gum the day before were quickly transported to the laboratory (within about 15 min) and mixed with four weights of anaerobic phosphate-buffered saline (PBS) in a 50-ml plastic tube. The PBS was boiled and cooled before it was used, to expel as much oxygen as possible. The diluted feces were squeezed through a paper filter to remove coarse particulate matter and dispensed (2 ml) into an incubation tube. There was little headspace in the tubes, so that anaerobiosis could be achieved. Since electricity was not available in the laboratory, the tubes were placed on one of the authors' abdomen and wrapped in a sheet of styrene foam to maintain the temperature as close to 37°C as possible. Fermentation was stopped at 0, 6, 12, 18, and 24 hr after fermentation was commenced by the introduction of 0.1 ml sulfuric acid ($\sim$37% w/w) and subsequent freezing in a kerosene freezer. Duplicate tubes were allotted to each incubation period, and fermentation without gum was conducted to estimate fecal endogenous fermentation.

The concentrations of carboxylic acids in the supernatants were determined after centrifugation ($10{,}000 \times g$ for 10 min) by high-performance liquid chromatography (HPLC), as described elsewhere [Ushida & Sakata, 1998]. The values obtained without gum were subtracted from those with gum to estimate the net production of acids from *A. zygia* gum. To estimate the resident time of *A. zygia* gum in the large intestine of the same chimpanzee, we followed her to check for residual gum in her feces.

### Cation Analyses by Induction-Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

The concentrations of various cations were measured in two samples of *A. zygia* gum with the use of ICP-AES. Two samples that originated from two different *A. zygia* trees were subjected to the analysis. The samples were dried to a constant weight and wet ashing was applied, as described elsewhere [Ohashi et al., 2004]. Aluminum, Ca, cadmium, cobalt, chromium, copper, iron, magnesium, manganese, nickel, potassium, lead, sodium, and zinc were analyzed by means of Vista Pro AX™ (Varian, Palo Alto, CA).

## RESULTS AND DISCUSSION

We found the gum exudates of *A. zygia* (DC) JF, *A. lebbeck* (L) Benth, *A. ferruginea* (Guill & Perr) Benth, *Sterculia tragacantha* Lind, and *Parkia bicolor* A. Chev. Of these, the gum of *A. zygia* was the most plentiful and easily found in the forests surrounding Bossou.

The ingestion of *A. zygia* gum by a female (Vélu) was observed and recorded at 11:40 A.M. This chimpanzee was also followed the next day. Her first feces in the morning (7:20 A.M.) were visually checked to determine whether there was any residual gum. Four pieces of residual gum (approximately 5 mm $\times$ 5 mm $\times$ 8 mm; Fig. 1C) were observed. A portion of the feces was sampled and used in a fermentation experiment. This chimpanzee defecated again at 1:39 P.M., and three similarly-sized pieces of residual gum were obtained. The estimated resident time of *A. zygia* gum in the digestive tract was therefore 20–26 hr. There is no significant difference in the mean retention times of fiber and the lower gut digesta turnover rate between humans and chimpanzees, though chimpanzees have a relatively larger lower gut volume than humans [Milton & Demment, 1988]. Since no other information regarding the resident time of the diet in the large intestine of chimpanzees is available, we used information obtained in humans. In humans, 70–80% of the total resident time is attributable to residence in the large intestine [Stevens & Hume, 1995]. If this is also true for chimpanzees, the resident time of *A. zygia* gum in the large intestine of chimpanzees can be estimated to be 13–15 hr by the first defecation, and 18–20 hr by the second defecation.

Since the weight of a piece of the residual gum in the feces was about 0.15 g (wet weight), approximately 1 g of gum was excreted in the feces in the two defecations. If this was the total gum mass excreted, and if one piece of gum exudate ingested was 30 g (about 20–30 g fresh weight of ingested exudate), degradation of the *A. zygia* gum was high. However, feces containing a large amount of gum have been observed at Bossou (Fujita, unpublished results). Accordingly, a determination of the true degradation rate of *A. zygia* gum requires additional study. *Albizia* gum contains 0.1–1% tannin and a small percentage of nitrogen, which contains various amino acids [Anderson & Morrison, 1990]. These components may affect the taste of the gum. Tannin in particular induces aversion [Takemoto, 2003]. The level of tannin reported for the leaves and stems of plants ingested by the wild chimpanzees in Bossou [Takemoto, 2003] is much lower than that reported for *Albizia* gums [Anderson & Morrison, 1990]. If tannin induces aversion, consumption of *Albizia* gum should be avoided by the chimpanzees. However, as mentioned above, they appear to actively select and ingest this gum. Therefore, there should be reasons for such selective ingestion despite the relatively higher tannin concentration.

The concentration of carboxylic acid (mmol/kg) found in the feces of the female chimpanzee is shown in Table I. The total acid concentration was 50.4 mmol/kg feces, which is similar to that in humans [Stevens & Hume, 1995]. The proportion of major SCFA was acetate: propionate: n-butyrate=62:20:6.

The fermentation traits of fresh *A. zygia* gum are shown in Fig. 2. Fermentation by fecal bacteria of the chimpanzee started with a 6-hr lag time and continued for as long as 18 hr. The total concentration (net concentration) of carboxylic acids reached 44 mmol/l within 18 hr of incubation. The most abundant end product was acetic acid, followed by lactic acid and propionic acid. Other carboxylic acids were produced in trace amounts. Since the estimated resident time of *A. zygia* gum in the large intestine ranges from 13 to 20 hr, the *A. zygia* gum must have been well fermented in the large intestine. If 1 g (fresh weight) of *A. zygia* gum is fermented for 18 hr in the large intestine of the chimpanzee, approximately 1 mmol of carboxylic acid can be produced. If one piece of *A. zygia* gum exudate (most likely 20–30 g in fresh weight) is ingested,

**TABLE I. Concentration (mmol/kg) and Molar Ratio (%) of Carboxylic Acids in the Feces of a Chimpanzee that Had Consumed *Albizia zygia* Gum 20 h Earlier**

| | Succinate | Lactate | Formate | Acetate | Propionate | Isobutyrate | Butyrate | Isovalerate | Valerate |
|---|---|---|---|---|---|---|---|---|---|
| Conc. | 0.1 | 0.3 | 1.3 | 31.4 | 10.0 | 1.2 | 2.9 | 1.7 | 1.5 |
| Molar ratio | 0.2 | 0.7 | 2.5 | 62.3 | 19.8 | 2.4 | 5.8 | 3.3 | 3.0 |

Carboxylic acids were determined on the feces of one female chimpanzee that had eaten *Albizia zygia* gum exudate approximately 20 h before defecation. For details, see text.

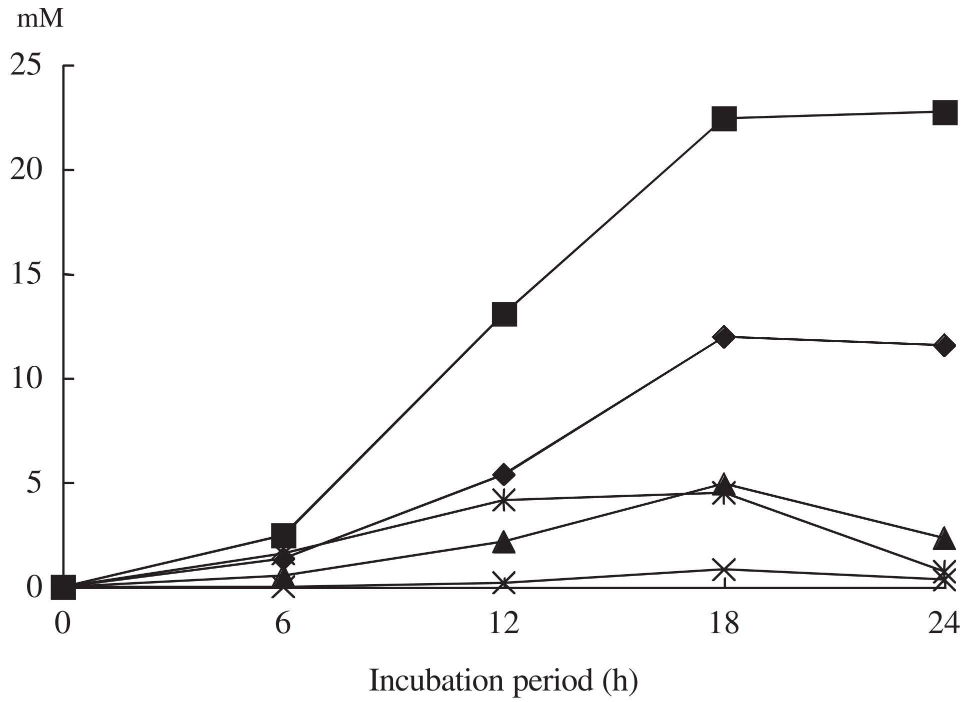



Fig. 2. Net production of carboxylic acid (in mM) from the in vitro fermentation of *A. zygia* gum by fecal bacteria of a wild chimpanzee (n=2). The values are the differences between those with substrate and those without substrate. ''Minor acids'' contain formate, isobutyrate, valerate, and isovalerate. For details, see text.

20–30 mmol carboxylic acid may be produced by fermentation. If the totality of these acids is absorbed by the intestinal mucosa, it may provide three kcal energy based on the energy value for carboxylic acid (3 kcal/g). We have little information about the daily energy requirements of chimpanzees in the wild; however, if they are similar to those of humans (2,000–3,000 kcal/d), the energy from the fermentation of a piece of *A. zygia* gum exudate ( ~ 3 kcal/piece of gum) is so small that the ingestion of gum alone would not contribute significantly to providing energy. If butyrate is produced, it may contribute to various physiological functions of the large intestine [Roediger, 1995; Sakata, 1997; Scheppach, 1994; Shimotoyodome et al., 2000; Tsukahara et al., 2003; Young & Gibson, 1995]. However, the major products were acetate, lactate, and propionate, which do not support the function of the large intestine as well as butyrate. Therefore, the contribution of *A. zygia* gum to the energy requirement of chimpanzees may be negligible.

The present in vitro fermentation work was done under field conditions in which certain types of equipment, such as an incubator and water bath, were lacking. Thus our ability to maintain temperature control was limited. Greater lactate production than propionate or butyrate production did not fit with the expected fecal SCFA proportion. Lactate is an intermediate metabolite in the fermentation process in the large intestine. It is converted to acetate and propionate, and to a lesser extent to butyrate by lactate-utilizing bacteria [Ushida et al., 2002]. Since this conversion produces equal molar amounts of the product,

**TABLE II. Cationic Composition of *Albizia zygia* Gum Exudate**

| Element | (μ g/g Dry matter) | | (mg/30 g Fresh matter) | |
|---|---|---|---|---|
| | Sample A | Sample B | Sample A | Sample B |
| Aluminum | 32 | 20 | 5 | 4 |
| Calcium | 15,090 | 8,700 | 2,154 | 1,633 |
| Cadmium | < 1.5 | < 1.3 | 0 | 0 |
| Cobalt | < 1.5 | < 1.3 | 0 | 0 |
| Chromium | 2.9 | < 1.3 | 0 | 0 |
| Copper | 8.8 | 7.9 | 1 | 1 |
| Iron | 26 | 7 | 4 | 1 |
| Magnesium | 2,490 | 1,845 | 355 | 346 |
| Manganese | 469 | 422 | 67 | 79 |
| Nickel | < 1.5 | < 1.3 | 0 | 0 |
| Potassium | 22,560 | 27,500 | 3,220 | 5,163 |
| Lead | < 2.9 | < 2.6 | 0 | 0 |
| Sodium | 108 | 83 | 15 | 16 |
| Zinc | 10 | 14 | 1 | 3 |

Two Albizia zygia gums originated from different trees were subjected to the analyes. The gum was dried and subjected to wet ashing. Cations were determined by ICP-AES. For details, see text.

the total amount of carboxylic acid estimated from this in vitro fermentation experiment is not modified even if whole lactate is converted to SCFA.

The cationic composition of *A. zygia* gum is shown in Table II. Ca, magnesium, and potassium were the components found in high concentration. This tendency was also true for other types of *Albizia* gum [Anderson & Morrison, 1990]. A high concentration of Ca is a remarkable characteristic of *A. zygia* gum that may explain why chimpanzees selectively ingest it. Little information about the daily requirement of minerals for chimpanzees in the wild is available. Only the recommended Ca concentration (0.55% on a dry matter basis) in the diet of nonhuman primates in general has been reported [National Research Council, 2003]. This level appears to be higher than that in humans [National Research Council, 2003]. If the chimpanzees' daily Ca requirement is similar to that of humans, a range of 600–800 mg of Ca would be required, depending on the sex and age of the animal. The present results suggest that one piece of *A. zygia* gum exudate (30 g) may contain a significant amount of Ca (1,600–2,000 mg, which is three to four times larger than the above-mentioned requirement) that can fulfill the daily requirement for that mineral even if the actual Ca requirement of chimpanzees is much higher than that of humans. A similar calculation suggests that the daily requirement of manganese, magnesium, and potassium can also be supplied. The major food for chimpanzees is fruit, which usually contains smaller amounts of Ca ( ~ 10 mg/100 g in the fresh, edible parts). However, African and Asian figs contain relatively high amounts of Ca (compared to figs in other parts of the world), so they may be a significant supplement for fruit-eating primates [O'Bryan et al., 1998]. Indeed, the consumption of figs is significant for chimpanzees at Bossou [Yamakoshi, 1998]. Although ingesting a small amount of *A. zygia* gum exudate may be an easier way to fulfill the daily requirement for these minerals, the Ca supplementation by plant gum exudates should be more carefully considered.

In humans, contamination by *Albizia* gum is carefully controlled by its high aluminum concentration, which may be involved in certain types of brain and dietary disorders [Bates et al., 1985]. At the moment, it is unclear whether this high aluminum content is a risk factor for the health of chimpanzees.


## ACKNOWLEDGMENTS

The authors are grateful to Professor T. Matsuzawa, Primate Research Institute, Kyoto University, for his valuable instructions on this field research. We are indebted to Messrs. P. Goumy, P. Cherif, and J. Dore for their assistance with the collection of gum exudates and chimpanzee feces, and to Ms. K.J. Hockings and Mr. J. Gamys for their valuable participation in discussions and their assistance with the on-site collection of materials. We are also indebted to Dr. T. Ogasawara and Mr. G. Katayama, SANEIGEN FFI, Inc., for the ICP analyses of the gum. We thank L'Institut de Recherche Environnementale de Bossou (IREB) and La Direction Nationale de la Recherche Scientifique et Technique (DNRST) of the government of the Republic of Guinea for their support. We are grateful to the anonymous reviewers whose valuable suggestions improved this paper.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