Spicing up the menu: evidence of fruit-feeding in *Galago moholi*

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Abstract

The African lesser bushbaby, *Galago moholi*, is currently described as a food specialist, feeding exclusively on small arthropods and gum primarily from *Acacia karroo* trees. We studied a population of *G. moholi* in a highly-fragmented habitat in the southernmost part of its natural distributional range in South Africa. In this habitat we opportunistically observed bushbabies feeding on fruits of the winter fruiting tree, *Pappea capensis.* Plot counts of tree composition revealed that although the dominant tree species in the area belonged to the genus *Acacia*, *A. karroo* trees were widely absent and gum could only be found in small quantities on other *Acacia* species. The analysis of *P. capensis* fruits showed high levels of protein, fat and energy content, making the fruits a potentially important food source for *G. moholi* during winter when insect availability is low. Our observation is the first documented case of fruit-feeding in *G. moholi*, suggesting that the species is not a food specialist as previously reported, but can opportunistically supplement its diet with fruit when available.

Key words: *Galago moholi*, feeding, fruits, food specialist, winter food source

Introduction

The African lesser bushbaby, *Galago moholi*, is a small (mean mass of adults: 200g), nocturnal and arboreal primate, which occurs across various habitat types such as *Acacia* woodlands, savannah woodlands and gallery forests throughout southern Africa (Bearder and Martin 1980; Nekaris and Bearder 2007). *G. moholi* has been described feeding exclusively on small arthropods and *Acacia* gum and there is currently no record of free-ranging *G. moholi* feeding on fruits as a natural food source in any region of its distribution. During the cold, dry season when arthropod densities greatly decrease, *G. moholi* increases its time spent on gum foraging to meet its energy demands (Bearder and Martin 1980; Harcourt 1986; Nash 1986; Nowack et al. 2013). To successfully digest the high amounts of β-polysaccharides found in both food sources, *G. moholi* has a specialized digestive tract, in which food matter retention allows for additional microbial fermentation (Caton et al. 2000). We studied the food sources utilised by *G. moholi* in a highly-fragmented habitat in the southernmost part of its distributional range in South Africa. Because of the limited amount of available gum sources in the region we hypothesize that the species must have unique feeding adaptations to survive in a region where an important winter food source (gum) is not readily available.

Methods

Study area

Fieldwork was conducted at Buffelsdrift Conservation Area (Pretoria, South Africa 25˚35’55.79’’ S, 28˚19’30.82’’ E). Buffelsdrift includes an area of about 5000 ha and is comprised of Marikana thornveld vegetation (Mucina and Rutherford 2006) interspersed with private houses, causing large-scale fragmentation of the natural habitat. The only primate species found in this region are the African lesser bushbaby, *Galago moholi*, and the vervet monkey, *Cercopithecus aethiops*, a diurnal primate feeding on a wide range of fruits, leaves and flowers (Wrangham and Waterman 1981). The South African National Biodiversity Institute classifies the area as semi-arid, sandy bushveld (Mucina and Rutherford 2006), with a hot, wet season (October–March) and a cold, dry season (April-September). The annual temperature (mean minimum and maximum temperature: T_{amin} and T_{amax}) and rainfall data were obtained for the study period from the South African Weather Service. In 2012, the coldest month at the study site occurred during June with a mean T_{amin} of 2.5 ± SD 2.5 °C. The maximum temperatures were recorded during January 2012 ($T_{a\ max}$: 30.4 ± SD 2.2 °C). Mean monthly temperatures during the study period between July and August 2012 remained relatively constant (T_{amin}: 3.2 ± SD 0.4 °C/ 6.1 ± SD 0.8 °C; T_{amax}: 21.2 ± SD 0.4 °C/ 24.6 ± SD 0.9 °C). Most of the rainfall (733.4 mm of 737.4 mm) was concentrated within the hot, wet season (January – May 2012 and October – December 2012). No rainfall was recorded during July 2012 to August 2012.

The study took place within the broader framework of a two-year project studying reproductive endocrinology via faecal samples in captive and free-ranging *G. moholi*. The study was approved by the Animal Use and Care Committee (EC056-12) of the University of Pretoria, South Africa.

Tree identification and plot counts

To evaluate the availability of gum and other possible feeding sources, such as fruits, we chose three transect plots of 30 m x 30 m (method according to Peet et al. 1998), at random locations within the study region. All trees within the transect plots were identified to species level and counted. We also documented whether trees were producing fruit or gum or both during the study period. For each gum-producing tree the availability and number of gum spots up to a height of two metres were determined.

Feeding observations

Identification of feeding sources of *G. moholi* was derived from opportunistic observations (*ad libitum* sampling, Altmann 1974) from July to August 2012. Earlier anecdotal observations, at Buffelsdrift, had suggested that *G. moholi* feeds on fruit of *Pappea capensis* trees (Mr. J. Mostert pers. comm.) and therefore we focused our observation efforts on feeding activity in the vicinity of *P. capensis* trees. *P. capensis* is a medium-sized deciduous tree, flowering from September to May and bearing fruits for one or two months between summer and spring (December – late August). Fruits consist of a shell covering a seed which is enclosed by a fleshy ariel. Both fruit and leaves are known to be used as food sources by various animal species, including a variety livestock and Bovidae species (Van Wyk et al. 2011; Karau et al. 2012). *P. capensis* trees are found in low densities and dispersed among the more abundant *Acacia* trees in the study region.

Observations were started in the vicinity of *P. capensis* trees at 1900 h. Individuals of *G. moholi* were located by shining headlamps to detect eyeshine. When spotted, bushbabies were followed on foot and the feeding behaviour documented. Bushbabies were followed as long as possible until we either lost the individual or until we came to a property boundary and were unable to follow the animal further. During animal follows we recorded every food item that was ingested, identifying arthropods to family level, and fruits and gum to species level. We did not mark individuals externally and were therefore unable to identify individuals.

The total amount of time spent searching for, and following, animals varied between 3 to 6 hours per night on consecutive nights (N=30 nights) for a total of 130 hours. Additionally, faecal samples collected from 20 adult free-ranging individuals (n=1/animal), caught in walk-in live traps constructed by the investigators, and analysed for signs of *P. capensis* seeds and shells. Animals were released at the same spot directly after capture.

Fruit analysis

We collected ~400 g of fruit samples from two *P. capensis* trees during August 2012. Fruit samples were oven dried at 40 ˚C for 4 days. Samples were weighed before and after drying to assess the moisture content. Samples were then transported to the University of Hamburg, Hamburg, Germany for biochemical analysis using standard methods. Total nitrogen content in the sample was determined using the Kieldahl procedure. Concentration of total crude protein (%) was subsequently calculated by multiplying the amount of total nitrogen with 6.25 (Génin et al. 2010). Concentration of crude lipids was determined by using an ANKOM XT 15l extractor (ANKOM Technology, Macedon NY, USA), extracting one gram of the sample material with petrol-ether in an ANKOM apparatus. The total amount of carbohydrates was determined by extracting 0.05 g of the sample using methanol (50 %) and subsequent decomposition of the solution through acid hydrolization (Kates 1972). A total of 0.1 g of the sample was used to determine the total amount of phenolics using a Folin-Ciocalteus-prepared-solution. The total amount of tannins present in the sample material was determined using a tannin-reagent (hydrochloric acid 37 %). The energy content of the fruit samples collected during this study was determined using an oxygen bomb calorimeter [6100 Parr instrument (Germany) GmbH, Frankfurt]. We used 0.6 g of each sample set for analyses.

Results

Tree identification, gum and fruit availability

In total we identified 284 trees belonging to 9 families and 14 species within the three transect areas (Tab.1). *Acacia* trees were the most abundant trees found (74 % of all trees counted), comprising five species, with *Acacia nilotica* (54 %) and *A. robusta* (27 %) making up the majority of the *Acacia* species. *A. karroo* was largely absent in the transect plots, accounting for only 1.5 % (1 tree) of *Acacia* trees.

Table 1: The family (N=9) and tree species (N=14) encountered within the three plots of the study area, their total abundance and whether they contained fruit or gum or both during the study period.

Family	Species	Quantity	Number of trees containing	
			Gum	Fruits
Mimosaceae	*Acacia nilotica*	112	6	-
Mimosaceae	*Acacia robusta*	55	10	-
Mimosaceae	*Acacia tortilis*	35	-	-
Rhamnaceae	*Ziziphus mucronata*	32	7	20
Sapindaceae	*Pappea capensis*	15	-	10
Mimosaceae	*Dichrostachys cinerea*	9	-	-
Anacardiaceae	*Searsia lancea*	7	-	-
Boraginaceae	*Ehretia rigida*	5	-	-
Rubiaceae	*Vangueria infaustia*	5	-	-
Mimosaceae	*Acacia caffra*	3	-	-
Combretaceae	*Terminalia sericea*	2	-	-
Ebenaceae	*Diospyros lycioides*	2	-	-
Caesalpiniaceae	*Peltophorum africanum*	1	-	-
Mimosaceae	*Acacia karroo*	1	-	-

Only 23 trees, across 3 species, showed signs of gum production on their trunk and branches (Tab.1): *A. nilotica* (10 trees), *A. robusta* (6 trees) and *Ziziphus mucronata* (7 trees). The majority of gum found in both *A. nilotica* and *A. robusta* species appeared old and heavily degraded. *Z. mucronata* trees displayed various wet gum spots, but spots were ≤ 1 cm in diameter.

Only two of the 14 tree species identified were found to be producing fruits during the study period: *Z. mucronata* and *P. capensis*. The majority of these trees were carrying fruits (*Z. Mucronata:* 62.5%*; P. capensis:* 66.67%) throughout the entire winter observation period (Tab. 1).

Feeding observations

We followed individual bushbabies on 39 different occasions during 30 nights of observation. The number of bushbabies followed per night varied between 0 and 4 animals. The animals were not externally marked and we cannot exclude that we followed an individual more than once. The average time spent following one animal was 40.5 ± SD 11.8 min. On 11 occasions we observed *G. moholi* in *P. capensis* trees; on three of these occasions *G. moholi* showed inquisitive behaviour (licking and smelling; average time: 14.7 ± 8.3s; mean ± SD) on fruits of *P. capensis*. Four of the 11 observations showed *G. moholi* feeding (masticating and ingesting) on the fruits. On these four occasions bushbabies spent an average time of 104 ± SD 26.9 s feeding on fruits and ate an average of 6 fruits (5.75 ± SD 0.96). We never saw bushbabies selectively feeding on larvae infesting the fruits. Additionally, traces of *P. capensis* shells were found in 90% (n=18/20, N= 9 males/ 9 females) of the collected faecal samples of free-ranging *G. moholi* during the end of winter. A total of seven bushbabies were spotted feeding on insects, all of which were Lepidoptera. We did not measure insect availability or the time spent foraging for arthropods, but our observations suggest that insect availability was significantly reduced during winter compared to that of summer periods. Gum feeding was observed on 79 occasions, during 21 animal follows, and was largely restricted to trees of *A. robusta* and, to a lesser degree, *A. nilotica* and *A. tortilis*. Feeding on the gum from *Z. mucronata* was observed for one animal, but we never saw the ingestion of fruits from this tree.

Table 2: Energy content and nutritional composition of *Pappea capensis* fruits collected at Buffelsdrift in August 2012.

Component	Mean ± SD
Moisture %	57.85 ± 4.2
Nitrogen (N) %	1.99 ± 0.03
Crude protein % (N × 6.25)	12.44 ± 0.17
Carbohydrates %	6.23 ± 1.05
Crude lipid %	39.30 ± 0.93
Condensed Tannin %	0.95 ± 0.08
Phenolics %	1.44 ± 0.34
Energy content (MJ/Kg)	26.26 ± 0.15

Pappea capensis fruit analysis

Fruits from *P. capensis* had a mass of 0.38 ± SD 0.09 g, mostly composed of moisture stored within the ariel, accounting for 57.82 ± SD 4.2% of the original fruit mass. Furthermore, the analyses of *P. capensis* fruits revealed that the fruits comprise mainly of crude lipids (~40 %), followed by considerably less crude protein and carbohydrates (each < 15 %) and also small amounts of phenolics and tannins (Tab. 2). The energy content of fruits was on average 26.26 ± SD 0.15 MJ/kg.

Discussion

The African lesser bushbaby inhabits a variety of environments in southern Africa. It is therefore not surprising that our study found that *G. moholi* does not only feed entirely on arthropods and gum as recorded in earlier studies (Bearder and Martin 1980; Harcourt 1986), but also supplements its diet with fruits. It has also long been known that fruit comprises an important part of the diet of captive *G. moholi* (Doyle and Bekker 1967; Lipschitz 1997).

Most studies on free-ranging *G. moholi* have been conducted within one region in the North-east of South Africa (coordinates 24°38.802'S–28°40.095'E; Bearder and Martin 1980; Harcourt 1986; Pullen et al. 2000; Nowack et al. 2013), which has an abundance of *A. karroo* trees, a species preferred by *G. moholi* for gum feeding (Bearder and Martin 1980; Harcourt 1986). Our study area is situated 182 km south of the aforementioned area and not only has no gum-producing *A. karroo*, but also lacks any other noteworthy gum-producing species. The comparatively dry conditions of the area, together with the low moisture and low topsoil quantity (www.SANBI.org; 13 January 2013), probably impede healthy growth of trees and as a result minimize the amount and quality of gum produced. This poses a problem for a species that usually utilizes gum as an important dietary component throughout the year (Bearder and Martin 1980; Harcourt 1986; Nowack et al. 2013). In regions with low gum-producing tree densities, *G. moholi* must either travel longer distances to find sufficient gum sources or find another food resource to satisfy its dietary needs, as for example the winter fruiting *P. capensis*.

G. moholi can selectively increase its gut retention time of gum, and thus the level of nutrient absorption, through the specialized ansa coli and elongated caecum (Caton et al. 2000). This mechanism also makes the digestion of plant matter such as fruits possible. The seeds of *P. capensis* have a soft, oily structure and can be assumed to be easily digested by *G. moholi.* As a consequence we found no remains of the seeds in the faecal samples collected during the winter period, however, traces of the hard shell were found in faeces which indicate that the shells seem to be indigestible to *G. moholi.*

Earlier studies on the feeding behaviour of free-ranging *G. moholi* have not reported the use of fruits (Bearder and Martin 1980; Harcourt 1986; Nash 1986). The majority of tree or bush species found throughout South Africa and northwards bloom between September and December, with fruits appearing during the summer to autumn period (Schmidt et al. 2002; Van Wyk et al. 2011), when gum and insect availabilities are high and no additional food sources are needed (Nowack et al. 2013). The fruiting period of *P. capensis* stretches from December to early August, depending on the latitude. As fruiting occurs relatively late in our study site (July-August) the tree provides a protein- and energy-rich food source for *G. moholi* during the colder months when insect densities have found to be low and gum is scarce in the current study area (Bearder and Martin 1980; Harcourt 1986; Nowack et al. 2013). The decrease of protein-rich arthropods during winter, coupled with the low protein concentration of ~1% found in *Acacia* gum (Harcourt 1986), could result in the use of protein-rich *P. capensis* fruits (~ 12%) by *G. moholi* to maintain key bodily functions which are dependent on protein such as growth, reproduction and general health within the species (Felton et al. 2009). The high energy content of *P. capensis* (~26 MJ/kg) fruits compared to that found in *Acacia* gum of 13 – 16 MJ/kg (Harcourt 1986; Nowack et al. 2013) also enables *G. moholi* to successfully meet its daily energy requirements, even when the availability of other food sources is low. In addition to the feeding observation on *P. capensis* fruits, individuals of another population of *G. moholi* were also observed feeding on flower parts (most probably nectar) of invasive blue gum trees (*Eucalyptus* spp.) that blossom during winter (J. Nowack, pers. comm.).

The results of this study show that the feeding pattern of *G. moholi* is not as fixed as previously described and that the species is able to adapt to a range of potential food sources. Our observation at Buffelsdrift is the first documented case of fruit-feeding in *G. moholi*, suggesting that the species is not a food specialist as originally thought, but rather able to supplement its diet with selected available food sources, such as fruits. Feeding on either gum or fruits during winter most probably accounts for the successful extension of *G. moholi* populations over a wider geographical range of southern Africa.

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