**Interannual variation in food choice of white-headed langur inhabiting limestone forests in Fusui, south-west Guangxi, China**

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# Abstract

Food habits are important factors for wild nonhuman primates’ environment adaptation. White-headed langurs (*Trachypithecus leucocephalus*) are endemic to the limestone forest and face to the habitat fragmentation, which have to adjust the food habits to adapt the special environment. In this study, we compared the dietary data for white-headed langurs living in Chongzuo White-headed Langur National Nature Reserve over two separate study periods to evaluate interannual variations in diet. Our results indicated that young leaves were the preferred major food for the langur. The plant parts consumption pattern was similar between the two separate study periods. The consumption of young leaves was varied with the availability of young leaves, whereas the consumption of mature leaves was negative correlated with the young leaf’s availability. The consumption of plant species and diet diversity varied in the two separate study periods, which were higher in 2013 than 2016. In both 2013 and 2016, the diet diversity varied with the consumption of mature leaves, but negative correlated with the consumption and availability of young leaves. Dietary interannual variation probably linked to the phenology variations, or probably mean that the white-headed langurs has a flexible ecological adaptation coping with habitat fragmentation.

**Key words:** Food choice, interannual variation, white-headed langurs; limestone forest

# 1 | INTRODUTION

Feeding accounts for the largest proportion of the daily activities of most primates species, including food choices, movement between food patches, feeding time budget, and so on (Fleagle, 2013). Feeding strategy is an important factor for wild nonhuman primates’ environment adaptation (Huang et al., 2008b). Most of wild primates adjust their food composition according to seasonal fluctuates of food availability in the environment (Richard, 1985). For example, the limestone-living rhesus macaques (*Macaca mulatta*) increased fruits consumption in the rainy season when the fruits are rich (Tang et al., 2016). The food composition of the sympatric François’ langur (*Trachypithecus francoisi*) and Assamese macaques (*Macaca assamensis*) varied in the seasonal changes, meanwhile, they gradually separate their dietary niche to decrease the interspecific competition (Zhou et al., 2018). Therefore, researches on the feeding contributes to the understanding of environment adaptation of wild primates.

Habitat loss and fragmentation are the greatest threats to animal protection, especially for those who living in highly fragmented forest habitats (Chaves et al., 2012). Habitat fragmentation usually changes the composition and structure of forest vegetation, descending the habitat quality, which lead to plant species number and diversity decreasing, and finally change the food distribution pattern and the quantity of animal food and (Arroyo-Rodríguez and Mandujano, 2006; Chiarello and Marsh, 2003; Fahrig, 2003). In fragmented habitats, the survival of primates depends greatly on their ability to respond to environmental changes, such as their behavior activities and the plasticity of eating habits (Wong and Sicotte, 2007), including increasing the type of food eaten to broaden the diet, increasing the proportion of low quality foods (mature leaves), and using more vines and secondary plants (Hu, 2011; Soule, 1986; Zhou et al., 2009). For example, spider monkeys（*Ateles geoffroyi*）in the forest habitat fragmentation of the south of Mexico, feed more plant species and leaves than those living in continuous forest (Chaves et al., 2012); *Alouatta pigra* in Kharak Mo area of Mexico also adopt similar strategies to cope with the habitat fragmentation (Rivera and Calmé, 2006). In the fragmented limestone forest, François’ langurs eat more vine (Li et al., 2012).

White-headed langur (*T. leucocephalus*) is a critically endangered primate species endemic to China. It is confined to a narrow triangular limestone hills in the four counties of Longzhou, Ningming, Jiangzhou and Fusui, in southwest Guangxi province, with a total area of about 200 km2 (Figure 1) (Huang, 2002). Limestone hills are vulnerable to human disturbance, which lead to habitat fragmentation. Terrestrial animals restricted to limestone hills, such as white-headed langurs, are particularly vulnerable to habitat degradation, which strongly impact their feeding strategy (Huang, 2002; Li, 2000; Marsh, 2003). Previous studies indicate that, probably due to the seasonal variation of food availability, the food diversity and composition of white-headed langurs varied seasonally, the langurs significantly increased the food diversity in the rainy season, and consumed more young leaves and less mature leaves in the rainy season than that of in the dry season (Huang et al., 2000; Huang et al., 2008b; Li and Rogers, 2006; Li et al., 2003; Yin et al., 2011; Zhou et al., 2013). In addition, as an adaptation strategy to fragmented habitat, white-headed langurs choose food species according to the dominance in the habitat to improve the feeding efficiency, and minimize the risk of predation (Zheng et al., 2020). However, these previous studies are limited to ≤1 yr., but the seasonal level and annual level variation of food resources in the environment probably exist due to the seasonal and interannual phenological changes (Zhou et al., 2009). In addition, the extent of habitat fragmentation varied year to year, which influence the food resources of the environment (Huang et al., 2008a). Therefore, the studies of the diet of the white-headed langurs in limestone habitats over the long term is necessary, which can not only explore the diet pattern and food choice strategy, but also understand the adaptation mechanisms to fragmentation environments.

In this paper, we examine interannual variation in dietary composition in the same white-headed langurs group at Chongzuo White-headed Langur National Nature Reserve in two separate study periods. We collected data on the diet of white-headed langurs to examine how animals had adjusted their feeding strategy as responses to fragmented limestone forests. We aim to confirm that what are the interannual variations in food parts, species composition, and food diversity of white-headed langurs, and what extent of dietary similarity over the two separate years.

# 2 | METHODS

## **2.1 | Study site and subjects**

The study site was located in the Chongzuo White-headed Langur National Nature Reserve, southwest Guangxi Province, China (22°24′–22°46′N, 107°22′–107°42′E; Figure 1). The reserve is characterized by limestone seasonal rainforests and the hills ranged from 400–600 m above sea level (Tan, 2014). The habitat of white-headed langurs is roughly divided into flat land, cliffs and hill top. As a result of long-term human activities, the habitat flat land among hills are converted to farmland, decreasing the continuity between hills. Some of the hills are completely fragmented (Huang et al., 2007). The vegetation on the limestone hills is severely disturbed. The reserve is partly surrounded by large-scale agricultural sugarcane plantations (Huang, 2002; Li and Rogers, 2004; Li and Rogers, 2005).

This study was carried out in two separate periods, January to December 2013 and January to December 2016. We collected climatic data, including minimum temperature and maximum temperature, using a thermometer (MX2301, HOBO), and rainfall via a rain gauge (MX2301, HOBO). Averaged annual rainfall was 977 mm in 2013 and 1022 mm in 2016, respectively. There are two distinct seasons: a rainy season from April to September with > 50 mm monthly rainfall and a dry season in the remainder of the year with < 50 mm monthly rainfall.

The study group had been semi-habituated to observers, they can tolerate the observers to observe within 20 m away. The study group initially consisted of 19 individuals (1 adult male, 9 adult females, and 10 immatures). The group size increased to 22 individuals following the birth of three infants in 2013. In 2016, when the observation began, the group was composed of 15 individuals (1 adult male, 8 adult females and 6 immatures), and increased to 18 individuals with the birth of three infants by the end of the study period. Since newborns did not feed plants, they were excluded throughout the study period.

## **2.2 | Data collection**

Since white-headed langur usually leave its sleeping site in the early morning about 6:00 am during the raining season and 7:00 am in the dry season (Huang et al., 2006). Accordingly, during each full-day follow, we began behavioral observation after locating the langurs near their sleeping sites at dawn and ended at nightfall, without losing contact with monkeys for more than 30 min. During each partial-day follow, we began data collection whenever we located the langurs, and ended when they disappeared for over 30 min or entered a sleeping site. Most of the partial-day follows occurred when langurs moved to the hilltops for resting at noon. We used scan sampling (Altmann, 1974) with 15-min intervals. The scans lasted 5 min, followed by 10 min of inactivity until the next scan began. We recorded the activity of each individual seen during each scan. We watched each individual for 5 s after detection and recorded its predominant behavior during that interval. To avoid sampling bias toward certain individuals or a particular age-sex class, we tried to collect behavioral records on as many different individuals as possible during a scan so that all individuals in the focal group were included, but we sampled no individual more than once during a scan. When the individual was feeding, we recorded plant species and parts eaten, e.g., mature leaves, young leaves, fruits, flowers, seeds, and petioles. When the maturity of some leave was unknown, we recorded the plant part as leaves unknown maturity. When some species cannot identify, we marked most plant species eaten and collected specimens for later identification. In total, we collected 2668 feeding records in 2013, 2528 of which were identified food items. In 2016, we collected 2599 feeding records for the same group, 2563 of which were identified food items.

We conducted vegetation surveys at the study site at the onset of behavioral data collection. We used a stratified random sampling method for placement of vegetation plots. We placed 13 plots (50×10 m) in the home range of the animals, including 4 at the valley basins and 9 on the hillsides. The plots covered most of the vegetation types. Within the plots, we tagged all trees with ≥ 5 cm diameter at breast height (DBH) and measured DBH. We determined the limit of 5 cm from a pilot observation showed that most foraging by langurs occurred in trees of this size and larger. We visually inspected all tagged trees (n = 312) within the vegetation plots in both 2013 and 2016 for the presence of young leaves, fruits, and flowers monthly to evaluate seasonal and interannual variation in plant part availability in the environment. We surveyed the phenology variation of all of the marked trees in the vegetation sample monthly, and recorded how the young leaves, mature leaves, flowers, and fruits were coming along. We used the method of Tweheyo et al. (2004) to estimate plant part score by classifying according to its cover of branches into five categories as follow: ≤ 10% cover (a tree with leaves that cover less than 10% of the branches), 10% and <25% cover, 25% and <50% cover, 50% and <75% cover, and 75% cover.

## **2.2 | Data analysis**

Following Heiduck (1997) we averaged the score from all marked trees in the phenological sample to represent the food availability index. We determined the percentage of different plant species in the diet by calculating the percentage of feeding records devoted to them among annual total feeding records. Food category composition was expressed as the percentage of different plant parts in the monthly diet of the study group using monthly total feeding records. Annual plant species was obtained by averaging the monthly percentages. We calculated the Shannon-Wiener diversity indices to represent the diversity of consumption of plant species. The Shannon-Weaver diversity index was calculated using the equation:

where *Ni* is the number of feeding records of *i*th plant species, *N* is the sum of feeding records of the plant species. Annual differences in food habits were determined using the overlap index (*OI*) (Whittaker and Fairbanks, 1958), which was calculated for all yearly combinations for each month. The OI varies from 0 (completely different) to 100 (complete overlap), and is defined by the equation:

where *Pa* and *Pb* are the feeding proportions (from 0 to 1) of a particular food item or category in years a and b, respectively. We calculated the OI separately for foods at the item and category levels.

We used Wilcoxon signed-rank test to examine interannual variations in the overall pattern of use of different plant species and parts. We used the Mann-Whitney *U* test to compare the monthly averages of the percentage of feeding records for various food items from rainy and dry seasons. We used Spearman rank correlation to test the relationship between the abundance and consumption of different plant species and parts. We ran all tests in SPSS 23.0, with significance levels of 0.05.

# 3 | RESULTS

## **3.1 | Food** **availability of study site**

In the habitat of white-headed langur, the plant part availability showed a similar monthly trend during the two study periods. In both years, young leaves were most available in March, when the mature leaves were most lacking. However, the overall availability of young leaves was significant higher in 2013 than in 2016 (*Z* = ─2.312, *n* = 11, *p* = 0.020; Figure 2a). The mature leaves, flowers, and fruits did not show the marked interannual variation between the two study periods (mature leaves: *Z* = ─ 0.711, *n* = 11, *p* = 0.477;flowers: *Z* = ─ 0.889, *n* = 11, *p* = 0.374; fruits: *Z* = ─ 0.800, *n* = 11, *p* = 0.424; Figure 2b, c, d).

In 2013, the flowers was significant more available in the rainy season than in the dry season (*Z* = ─ 2.653, *n* = 11, *p* = 0.008), the other plant part availability did not show significant seasonal variation (young leaves: *Z* = ─ 1.643, *n* = 11, *p* = 0.100; mature leaves: *Z* = ─1.278, *n* = 11, *p* = 0.201; fruits: *Z* = ─ 1.095, *n* = 11, *p* = 0.273). In 2016, mature leaves and flowers were significant more available in the rainy season than in the dry season (mature leaves: *Z* = ─2.556, *n* = 11, *p* = 0.011; flowers: *Z* = ─ 2.008, *n* = 11, *p* = 0.045), the availability of young leaves and fruits did not show significant seasonal variation (young leaves: *Z* = ─1.643, *n* = 11, *p* = 0.100; fruits: *Z* = ─ 0.091, *n* = 11, *p* = 0.927).

## **3.2 | Plant parts consumption of white-headed langurs**

White-headed langurs took leaves as major food in both 2013 and 2016, of which young leaves were the majorities. In 2013, the consumption of plant parts was followed by mature leaves, fruits, stems, flowers, seeds, others, and petioles. In 2016, the consumption of fruits was higher than mature leaves, followed by seeds, stems, flowers, and others. Petioles almost were not recorded in 2016 (Table 1). The consumptions of leaves, young leaves, mature leaves, fruits, young fruits, mature fruits, seeds, petioles, and others were no significant interannual difference between 2013 and 2016. The interannual variations are mainly reflected in leaves unknown maturity, fruits unknown maturity, flowers, and stems (Table 2). The overlap index of food items in both year was from 48.81 to 90.59, where the highest value appeared in May and the lowest in July (Figure 3), a total of 8 months greater than 70%. for In summary, the white-headed langurs had similar food item composition in the two study periods.

The seasonal variation of plant parts consumption mainly reflected in leaves. In 2013, the seasonal variation marked in young leaves, mature leaves, stems, and petioles, the other food items did not show significant seasonal difference. The consumption of young leaves was significant higher in the rainy season than that of in the dry season, contrary to the seasonal variation of mature leaves, stems, and petioles (Table 2). In 2016, significant seasonal variation showed in mature leaves, young fruits, and seeds. The mature leaves and seeds were consumed more in the dry season than that of in the rainy season, whereas the young fruits were consumed more in the rainy season. No significant difference is found in the other food items (Table 2).

**Table 1** Monthly percentage of feeding records devoted to different plant parts of 2013 and 2016 in .Chongzuo White-headed Langur National Nature Reserve.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Months | Leaves | Young leaves | Mature leaves | Leaves unknown maturity | Fruits | Young fruits | Mature fruits | Fruits unknown maturity | Stems | Seeds | Flowers | Petioles | Others |
| 2013 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Jan | 86.3 | 29.0 | 54.1 | 3.3 | 2.2 | 0.8 | 0.3 | 1.1 | 7.7 | 0.3 | 3.0 | 0.5 | 0 |
| Mar | 75.9 | 73.0 | 1.9 | 1.0 | 2.4 | 1.1 | 1.3 | 0 | 5.8 | 1.1 | 14.9 | 0 | 0 |
| Apr | 84.0 | 77.8 | 5.2 | 1.0 | 10.3 | 9.9 | 0.4 | 0 | 1.6 | 0.4 | 3.7 | 0 | 0 |
| May | 92.7 | 85.8 | 6.7 | 0.2 | 2.3 | 2.2 | 0.1 | 0 | 2.7 | 0 | 2.0 | 0 | 0.3 |
| Jun | 78.0 | 75.3 | 0.7 | 2.0 | 7.6 | 5.9 | 0 | 1.7 | 2.5 | 0 | 3.9 | 0 | 8.0 |
| Jul | 31.8 | 30.4 | 0.8 | 0.6 | 52.9 | 51.2 | 1.7 | 0 | 5.4 | 6.8 | 3.0 | 0 | 0.2 |
| Aug | 61.5 | 59.7 | 1.4 | 0.4 | 33.2 | 29.9 | 2.1 | 1.3 | 2.7 | 0.3 | 2.1 | 0 | 0.3 |
| Sep | 63.6 | 59.3 | 3.7 | 0.6 | 9.2 | 8.7 | 0.2 | 0.3 | 6.6 | 4.1 | 16.5 | 0 | 0 |
| Oct | 63.2 | 53.3 | 9.7 | 0.1 | 12.9 | 9.2 | 3.6 | 0.1 | 13.7 | 2.9 | 7.2 | 0.1 | 0 |
| Nov | 46.3 | 21.0 | 24.7 | 0.6 | 8.4 | 7.1 | 1.1 | 0.1 | 21.0 | 9.2 | 14.8 | 0.3 | 0 |
| Dec | 67.5 | 11.9 | 55.6 | 0 | 1.1 | 0.3 | 0.5 | 0.3 | 24.3 | 4.7 | 2.1 | 0 | 0.2 |
| Annual Mean | 68.3 | 52.4 | 14.9 | 0.9 | 12.9 | 11.5 | 1.0 | 0.5 | 8.5 | 2.7 | 6.6 | 0.1 | 0.8 |
| Annual SD | 18.0 | 25.4 | 20.9 | 1.0 | 16.0 | 15.5 | 1.1 | 0.6 | 7.8 | 3.2 | 5.8 | 0.2 | 2.4 |
| Dry season Mean | 67.8 | 37.6 | 29.2 | 1.0 | 5.4 | 3.7 | 1.4 | 0.3 | 14.5 | 3.7 | 8.4 | 0.2 | 0 |
| Dry season SD | 14.9 | 25 | 24.8 | 1.3 | 5.1 | 4.1 | 1.3 | 0.4 | 8.1 | 3.6 | 6.2 | 0.2 | 0.1 |
| Rainy season Mean | 68.6 | 64.7 | 3.1 | 0.8 | 19.2 | 18 | 0.7 | 0.5 | 3.6 | 1.9 | 5.2 | 0 | 1.5 |
| Rainy season SD | 21.6 | 19.8 | 2.5 | 0.7 | 19.6 | 18.9 | 0.9 | 0.8 | 2.0 | 2.9 | 5.6 | 0 | 3.2 |
| 2016 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Jan | 83.9 | 23.3 | 60.6 | 0 | 1.4 | 1.4 | 0 | 0 | 9.6 | 4.8 | 0.3 | 0 | 0 |
| Mar | 92.9 | 90.5 | 2.2 | 0.2 | 2.4 | 2.4 | 0 | 0 | 0.2 | 2.0 | 2.6 | 0 | 0 |
| Apr | 66.0 | 59.1 | 6.8 | 0 | 30.1 | 23.4 | 6.6 | 0 | 0.4 | 0.4 | 2.9 | 0 | 0.2 |
| May | 94.5 | 94.5 | 0 | 0 | 2.9 | 2.9 | 0 | 0 | 1.6 | 0 | 1.0 | 0 | 0 |
| Jun | 87.3 | 87.3 | 0 | 0 | 7.6 | 7.6 | 0 | 0 | 0.2 | 0 | 1.7 | 0 | 3.2 |
| Jul | 82.4 | 81.1 | 1.3 | 0 | 14.4 | 14.1 | 0.4 | 0 | 0.9 | 0.8 | 1.5 | 0 | 0 |
| Aug | 78.5 | 72.0 | 6.5 | 0 | 21.0 | 20.5 | 0.5 | 0 | 0.5 | 0 | 0 | 0 | 0 |
| Sep | 69.9 | 64.2 | 5.6 | 0 | 23.4 | 23.4 | 0 | 0 | 0.3 | 0.5 | 5.9 | 0 | 0 |
| Oct | 56.1 | 49.5 | 6.6 | 0 | 26.4 | 18.4 | 8.0 | 0 | 0 | 17.5 | 0 | 0 | 0 |
| Nov | 74.5 | 54.7 | 19.8 | 0 | 4.1 | 1.0 | 3.1 | 0 | 3.6 | 12.6 | 5.3 | 0 | 0 |
| Dec | 64.2 | 41.5 | 22.7 | 0 | 2.2 | 2.2 | 0 | 0 | 15.7 | 14.4 | 2.6 | 0 | 0.9 |
| Annual Mean | 77.3 | 65.2 | 12.0 | 0 | 12.3 | 10.7 | 1.7 | 0 | 3.0 | 4.8 | 2.2 | 0 | 0.4 |
| Annual SD | 12.3 | 22.4 | 17.8 | 0.1 | 11.0 | 9.4 | 2.9 | 0 | 5.1 | 6.7 | 2.0 | 0 | 1.0 |
| Dry season Mean | 74.3 | 51.9 | 22.4 | 0 | 7.3 | 5.1 | 2.2 | 0 | 5.8 | 10.3 | 2.2 | 0 | 0.2 |
| Dry season SD | 14.7 | 24.6 | 23.0 | 0.1 | 10.7 | 7.5 | 3.5 | 0 | 6.8 | 6.6 | 2.1 | 0 | 0.4 |
| Rainy season Mean | 79.8 | 76.4 | 3.4 | 0 | 16.6 | 15.3 | 1.2 | 0 | 0.7 | 0.3 | 2.2 | 0 | 0.6 |
| Rainy season SD | 10.7 | 13.7 | 3.3 | 0 | 10.2 | 8.7 | 2.6 | 0 | 0.5 | 0.3 | 2.1 | 0 | 1.3 |

**Table 2** Interannual and seasonal variation of plant parts consumed by white-headed langurs in the 2013 and 2016. (Wilcoxon signed-rank test for interannual variation, *n* = 11; Mann Whitney *U* test for seasonal variation, *n* = 11)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Variation |  |  | Leaves | Young leaves | Mature leaves | Leaves unknown maturity | Fruits | Young fruits | Mature fruits | Fruits unknown maturity | Stems | Seeds | Flowers | Petioles | Others |
| Annual |  | *Z* | -1.245 | -1.867 | -0.356 | -2.803 | -0.178 | -0.711 | -0.051 | -2.366 | -2.667 | -0.889 | -2.845 | -1.604 | -0.734 |
|  |  | *p* | 0.213 | 0.062 | 0.722 | 0.005 | 0.859 | 0.477 | 0.959 | 0.018 | 0.008 | 0.374 | 0.004 | 0.109 | 0.463 |
| Seasonal | 2013 | *Z* | -0.183 | -2.008 | -2.191 | -0.183 | -1.461 | -1.826 | -1.095 | -0.093 | -2.556 | -1.281 | -0.730 | -2.090 | -1.593 |
|  |  | *p* | 0.855 | 0.045 | 0.028 | 0.855 | 0.144 | 0.068 | 0.273 | 0.926 | 0.011 | 0.200 | 0.465 | 0.037 | 0.111 |
|  | 2016 | *Z* | -0.730 | -1.826 | -2.013 | -1.095 | -1.643 | -2.191 | -0.100 | - | -0.548 | -2.764 | -0.091 | - | -0.464 |
|  |  | *p* | 0.465 | 0.068 | 0.044 | 0.273 | 0.100 | 0.028 | 0.921 | - | 0.584 | 0.006 | 0.927 | - | 0.642 |

**Table 3** Correlation analysis between the consumption and the availability of plant parts (*n* = 11)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Availability |  | Leaves | Young leaves | Mature leaves | Leaves unknown maturity | Fruits | Young fruits | Mature fruits | Fruits unknown maturity | Stems | Seeds | Flowers | Petioles | Others |
| 2013 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Young leaves | r | 0.109 | 0.718 | -0.836 | 0.345 | 0.300 | 0.300 | -0.145 | -0.386 | -0.736 | -0.305 | 0.273 | -0.595 | 0.188 |
|  | p | 0.750 | 0.013 | 0.001 | 0.298 | 0.370 | 0.370 | 0.670 | 0.241 | 0.01 | 0.361 | 0.417 | 0.053 | 0.579 |
| Mature leaves | r | -0.573 | 0.009 | -0.345 | -0.382 | 0.727 | 0.700 | 0.273 | 0.223 | -0.027 | 0.118 | 0.173 | -0.040 | 0.109 |
|  | p | 0.066 | 0.979 | 0.298 | 0.247 | 0.011 | 0.016 | 0.417 | 0.509 | 0.937 | 0.729 | 0.612 | 0.906 | 0.750 |
| Flowers | r | 0.278 | 0.784 | -0.506 | 0.036 | 0.387 | 0.492 | -0.351 | -0.378 | -0.779 | -0.411 | -0.082 | -0.507 | 0.216 |
|  | p | 0.408 | 0.004 | 0.113 | 0.915 | 0.239 | 0.124 | 0.290 | 0.252 | 0.005 | 0.209 | 0.811 | 0.111 | 0.523 |
| Fruits | r | -0.473 | 0.209 | -0.855 | 0.009 | 0.464 | 0.382 | 0.173 | 0.098 | -0.273 | -0.014 | 0.327 | -0.439 | 0.357 |
|  | p | 0.142 | 0.537 | 0.001 | 0.979 | 0.151 | 0.247 | 0.612 | 0.775 | 0.417 | 0.968 | 0.326 | 0.176 | 0.281 |
| 2016 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Young leaves | r | 0.345 | 0.745 | -0.688 | 0.500 | 0.318 | 0.491 | -0.03 | - | -0.564 | -0.523 | -0.050 | - | 0.012 |
|  | p | 0.298 | 0.008 | 0.019 | 0.117 | 0.340 | 0.125 | 0.931 | - | 0.071 | 0.099 | 0.884 | - | 0.973 |
| Mature leaves | r | 0.045 | 0.409 | -0.579 | -0.500 | 0.555 | 0.591 | 0.154 | - | -0.245 | -0.651 | -0.251 | - | 0.058 |
|  | p | 0.894 | 0.212 | 0.062 | 0.117 | 0.077 | 0.056 | 0.652 | - | 0.467 | 0.030 | 0.457 | - | 0.866 |
| Flowers | r | 0.436 | 0.700 | -0.601 | 0.300 | 0.191 | 0.464 | -0.292 | - | -0.309 | -0.706 | 0.205 | - | 0.283 |
|  | p | 0.180 | 0.016 | 0.050 | 0.370 | 0.574 | 0.151 | 0.383 | - | 0.355 | 0.015 | 0.545 | - | 0.399 |
| Fruits | r | 0.436 | 0.445 | -0.451 | 0.300 | -0.400 | -0.436 | -0.258 | - | 0.018 | -0.046 | -0.068 | - | 0.295 |
|  | p | 0.180 | 0.170 | 0.164 | 0.370 | 0.223 | 0.180 | 0.444 | - | 0.958 | 0.893 | 0.842 | - | 0.379 |

There was a correlation between food items consumption of white-headed langurs and food availability in this study (Table 3). The consumption of young leaves was significant positively correlative with the young leaves and flowers’ availability, and negatively with the mature leaves’ availability in both years. In 2013, the feeding proportion of mature leaves was marked negatively correlative with the availability of fruits; the fruits were positively correlative with the mature leaves’ availability, especially the young fruits; the stems were negatively correlation with the availability of young leaves and flowers. In 2016, the feeding proportion of seeds was significant negatively correlative with the availability of mature leaves and flowers.

## **3.3 | Plant species diversity and composition consumed by white-headed langurs**

The average indexes of food diversity were 4.02 ± 0.28 in 2013, and 3.48 ± 0.39 in 2016, respectively. The food diversity showed significant interannual differences (Figure 4). The food diversity of 2013 was significantly higher than that of 2016 (*Z* = -2.578, *n* = 11, *p* = 0.010). No significant seasonal difference was found in the food diversity in 2013 (*Z* = -1.643, *n* = 11, *p* = 0.100), while in 2016 the food diversity was significantly higher during the dry season than during the rainy season (*Z* = -2.008, *n* = 11, *p* = 0.045).

Langurs had a considerable number of species in their diet. They consumed 93 plant species in 2013 and 70 species in 2016 (Figure 5). Of which 60 species were consumed in both years, accounting for 64.52% of the total food species in 2013 and 85.71% of that in 2016. The consumption of plant species of 2013 was significantly higher than that of in 2016 (*Z* = -2.941, *n* = 11, *p* = 0.003). However, no marked seasonal difference of the plant species was found in the two study periods (2013: *Z* = -0.735, *n* = 11, *p* = 0.462; 2016: *Z* = -0.926, *n* = 11, *p* = 0.355). The overlap of plant species between the two periods peaked in August at 61.50%, and lowest peaked in May at 32.03% (Figure 6).

The correlation analysis indicated that the number of plant species consumed and food diversity did not show a significant correlation with the plant part availability in 2013 (Table 4). However, in 2016, the number of plant species marked positively correlative with the consumption of flowers, the food diversity positively correlative with the consumption of mature leaves, negative with the consumption and availability of young leaves (Table 4).

**Table 4** Correlation analysis between the number of plant species and the consumption and availability of plant part, and the relationship between the food diversity and the consumption and availability of plant part

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Number of plant species | | | | |  | Food diversity | | | | |
|  | 2013 | |  | 2016 | |  | 2013 | |  | 2016 | |
|  | r | p |  | r | p |  | r | p |  | r | p |
| Consumption of plant part |  |  |  |  |  |  |  |  |  |  |  |
| Leaves | 0.037 | 0.915 |  | -0.120 | 0.726 |  | 0.427 | 0.190 |  | -0.409 | 0.212 |
| Young leaves | -0.005 | 0.989 |  | -0.143 | 0.675 |  | -0.064 | 0.853 |  | -0.718 | 0.013 |
| Mature leaves | 0.064 | 0.852 |  | 0.236 | 0.486 |  | 0.391 | 0.235 |  | 0.692 | 0.018 |
| Leaves unknown maturity | -0.252 | 0.455 |  | 0.304 | 0.363 |  | 0.018 | 0.958 |  | -0.200 | 0.555 |
| Fruits | -0.005 | 0.989 |  | -0.046 | 0.893 |  | -0.500 | 0.117 |  | -0.291 | 0.385 |
| Young fruits | -0.114 | 0.738 |  | -0.240 | 0.478 |  | -0.591 | 0.056 |  | -0.518 | 0.102 |
| Mature fruits | 0.233 | 0.490 |  | 0.0150 | 0.965 |  | -0.100 | 0.770 |  | 0.040 | 0.908 |
| Fruits unknown maturity | 0.068 | 0.843 |  | - | - |  | 0.228 | 0.500 |  | - | - |
| Stems | 0.284 | 0.398 |  | -0.106 | 0.756 |  | 0.382 | 0.247 |  | 0.300 | 0.370 |
| Seeds | -0.089 | 0.794 |  | 0.214 | 0.528 |  | -0.246 | 0.466 |  | 0.560 | 0.073 |
| Flowers | 0.211 | 0.534 |  | 0.741 | 0.009 |  | 0.164 | 0.631 |  | 0.310 | 0.354 |
| Petioles | 0.125 | 0.714 |  | - | - |  | 0.393 | 0.232 |  | - | - |
| Others | -0.284 | 0.397 |  | 0.419 | 0.199 |  | -0.292 | 0.383 |  | 0.405 | 0.217 |
| Availability of plant part |  |  |  |  |  |  |  |  |  |  |  |
| Young leaves | -0.069 | 0.841 |  | -0.041 | 0.904 |  | -0.255 | 0.450 |  | -0.727 | 0.011 |
| Mature leaves | 0.243 | 0.472 |  | -0.415 | 0.205 |  | -0.155 | 0.650 |  | -0.473 | 0.142 |
| Flowers | 0.011 | 0.973 |  | 0.014 | 0.968 |  | -0.237 | 0.483 |  | -0.564 | 0.071 |
| Fruits | 0.082 | 0.810 |  | 0.161 | 0.636 |  | -0.236 | 0.484 |  | -0.055 | 0.873 |

They foraged similar species during the two study periods. There was also marked similarity in the percentages of feeding records for plant species between the two study periods. Of the top 10 food species, 6 species (*Pteroceltis tatarinowii*, *Canthium dicoccum*, *Cansjera rheedei*, *Sterculia monosperma*, *Ventilago inaequilateralis* and *Ficus microcarpa*) were presented in the list of top 10 food species during both study periods (Table 5). Of which the *Pteroceltis tatarinowii* wasconsumed in large quantities in both years, and consumed every month during the recording period. The main part of *Pteroceltis tatarinowii* was young leaves and mature leaves. Thus, these species were the major foods for the langurs.

# 4 | DISCUSSION

White-headed langurs are typical limestone forest folivores and take young leaves as major food (Chivers and Hladik, 1980; Li and Rogers, 2006; Yin et al., 2011; Zhou et al., 2013). In this study, the plant parts composition in the two study periods is similar, the leaves are by far the most proportion. The consumption of leaves shows significant seasonal differences, the young leaves were the major food items, which was significantly consumed more in the rainy season in 2013. This result is similar with other researches of white-headed langurs (Huang et al., 2008b; Li and Rogers, 2006; Yin et al., 2011). Meanwhile, the consumption of young leaves was confirmed to correlate positively with their availability, which is similar to other studies that the consumption of prefer foods vary with the seasonal variations of the prefer foods availability (Chaves et al., 2012; Tsuji et al., 2006).

Most of wild primates prefer to choose the food that easily available, thus to conserve energy (Richard, 1985). In this study, however, even though the mature leaves were abundant and essentially available, they were consumed more as fallback food in the dry season when the young leaves were lack, due to the mature leaves poor in nutrition and rich in fiber, that lead to poor palatability (Li et al., 2013; Oftedal, 1991; Richard, 1985). The same results are obtained in other white-headed langurs’ studies (Huang et al., 2008b; Li and Rogers, 2006; Zhou et al., 2013). François’ langurs also

**Table 5** The top 10 plant species consumed by white-headed langurs in 2013 and 2016 in Chongzuo White-headed Langur National Nature Reserve.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | Family | Life form | 2013 | | |  | 2016 | | |
| Plant parts | No. of months used | %(F)b |  | Plant parts | No. of months used | %(F) |
| *Pteroceltis tatarinowii* | Ulmaceae | Tree | YL, ML | 11 | 14.8 |  | YL, ML | 11 | 18.0 |
| *Cuscuta chinensis* | Convolvulaceae | Vine | FL, ST | 11 | 8.4 |  |  |  |  |
| *Canthium dicoccum* | Rubiaceae | Tree | YL, ML, FR, FL | 11 | 8.2 |  | YL, ML, FR, FL | 7 | 3.6 |
| *Cansjera rheedei* | Opiliaceae | Vine | YL, ML, FR, S, ST | 11 | 5.7 |  | YL, ML, FR | 11 | 7.0 |
| *Sterculia monosperma* | Sterculiaceae | Tree | YL, FR | 11 | 4.4 |  | YL, FL,FR,S | 7 | 4.1 |
| *Ventilago inaequilateralis* | Rhamnaceae | Vine | YL, FR | 11 | 3.9 |  | YL, FR, FL, | 8 | 5.7 |
| *Sinosideroxylon pedunculatum* | Sapotaceae | Tree | YL, ML, FR | 8 | 3.6 |  |  |  |  |
| *Ficus microcarpa* | Moraceae | Tree | YL, FR | 10 | 3.5 |  | YL, FR | 8 | 3.2 |
| *Gymnema sylvestre* | Asclepiadaceae | Vine | YL, ML, FR, FL | 11 | 3.1 |  |  |  |  |
| *Broussonetia papyrifera* | Moraceae | Tree | YL, ML, FR, FL | 9 | 2.5 |  | YL, ML, FR, FL | 8 |  |
| *Iodes vitiginea* | Icacinaceae | Vine |  |  |  |  | YL, ML, FR, FL | 10 | 7.8 |
| *Vitex tripinnata* | Verbenaceae | Tree |  |  |  |  | YL, FR | 8 | 5.9 |
| *Bauhinia championii* | Caesalpiniaceae | Vine |  |  |  |  | YL, S | 7 | 4.8 |
| *Apodytes dimidiata* | Icacinaceae | Tree |  |  |  |  | YL, ML, FR, FL | 11 | 4.0 |
| Sum of top 10 food species |  |  |  |  | 58.1 |  |  |  | 64.3 |

a Plant part: YL, young leaf; ML, mature leaf; FR, fruit; S, seed; FL, flower; ST, stem  
b %(F): percentage of total feeding record

are typical folivores that consume young leaves mostly, and supplementary mature leaves in the dry season (Hu, 2011; Huang et al., 2010; Zhou et al., 2009). Rhesus macaque that live in limestone forest are folivorous, and their consumption of young leaves is the highest, and varies with the seasonal variation of the availability of young leaves, in the rainy season when the young leaves are rich, they barely feed on mature leaves (Tang et al., 2016).

Except for the mature leaves, seed, stems, and petioles also consumed increased as fallback food in the dry season. Many researchers report that primates increase the consumption of seed, stems, and petioles to supplement with the prefer foods lacking (Amato et al., 2015; Hu, 2011; Huang et al., 2008b; Huang et al., 2010). Such as François’ langurs increase the consumption of stems and seeds in the dry season (Huang et al., 2010; Tang et al., 2016; Zhou et al., 2009). In this study, the consumption of seeds significantly increased in the dry season of 2016, whereas stems and petioles were the significant supplementary foods in the dry season of 2013. Seeds were the important supplementary foods that rich in fats and starch in the young leaves scarce season, these high-quality foods are the important energy resource for primates (Richard, 1985). Although this study did not calculate the availability of seeds, studies have shown that seed yields are susceptible to climate and show significant interannual variability (Zhou et al., 2009). The increasing of consumption of stems and petioles in the dry season of 2013 may be related with the rainfall, which was lower in 2013 than in 2016. The stems and petioles have relative higher moisture (Waterman and Kool, 1994), so the plant parts that rich in water were the better choices in the lower rainfall period.

In general, foods diversity is influenced by the consumption and availability of prefer foods, when the wild animals spend most time in the several staple foods species, the diversity of diet would be reduced (Bennett, 1986; Fleagle, 1984; Li et al., 2009; Li et al., 2003). In this study, the data of 2016 showed that when these langurs increased the consumption of young leaves, the diversity of diet was decreased, however, the consumption of mature leaves was correlated positively with the diversity. This is likely to indicate that during the rainy season, the langurs are more concentrated on feeding in several plants with abundant young leaves. For example, *Pteroceltis tatarinowii*, *Sterculia monosperma*, *Ficus microcarpa*, *Iodes vitiginea*, *Vitex tripinnate*, and *Ventilago inaequilateralis* were the main sources of young leaves for these langurs, especially *Pteroceltis tatarinowii*, *Sterculia monosperma*, and *Ficus microcarpa* were the most feeding species in the rainy season in both years (Table 5). In the dry season, the feeding records of leaves’ species were more uniform. Research on François’ langurs also indicates that the negative correlation between the diet diversity and consumption of young leaves (Li et al., 2008). Compared with frugivorous, the folivore primates have lower diet diversity, such as the diversity indices of *Lemur catta* and *Propithecus diadema perrieri* were range on 6.37~6.51 and 6.12~6.35 respectively (Lehman and Mayor, 2004), which is significant higher than white-headed langurs (2.67~4.39; in this study) and François’ langurs (1.76~2.53)(Li et al., 2008). This probably due to relative higher availability of leaves. The lower diet diversity may be the adaptation strategy for the fragment habitat (Li et al., 2015).

The interannual analysis show significant variations in plant species and diversity between different study periods, the overlap indices for the plant species during the two separate periods were relatively lower and the highest month was only 61.5%. François’ langurs living in Nonggang Nature Reserve also show significant interannual variations on the consumption of plant species (Zhou et al., 2009). This is probably because of the differences in phenology between the two study periods. The decrease of diet diversity and plant species consumption probably mean that these white-headed langurs improve the adaptation of the fragmentation, however, the promotion of adaptation need further research.

In summary, our results confirm that the consumption of young leaves in white-headed langurs varied with the young leaves availability, the mature leaves were the supplementary food in the dry season when the young leaves were lacking. Diet diversity was decrease in the rainy season may be related to the increase of young leaves’ consumption. There were significant interannual variations in the plant species consumption of the langur diet, which probably related to the variations of phenology.

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# CONFLICT OF INTERESTS

None declared

# AUTHOR CONTRIBUTIONS

L.Y.B. and L.C.H designed the research. L.S.Y and C. T. collected and analyzed data and wrote the manuscript. L.Y.B and H.Z.H revised the manuscript.

# DATA AVAILABILITY STATEMENT

All data are available in the in the figshare repository at https://doi. org/10.6084/m9.figshare.12979889.v1

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# FIGURE LEGENDS

**Figure 1.** Maps showing locations of study site where we studied the diet of White-headed langurs.

**Figure 2.**  Monthly abundance of young leaves (a), mature leaves (b), fruits (c), and flowers (d) in Fusui study site in 2013 and 2016.

**Figure 3.** Seasonal changes in plant part overlap index (OI) values for foods eaten by White-headed langurs in 2013 and 2016.

**Figure 4.** Monthly changes in diversity of plant species consumed by white-headed langurs in 2013 and 2016.

**Figure 5.**  Number of plant species consumed by white-headed langurs in 2013 and 2016.

**Figure 6.** Seasonal changes in plant species overlap index (OI) values for foods eaten by white-headed langurs in 2013 and 2016.

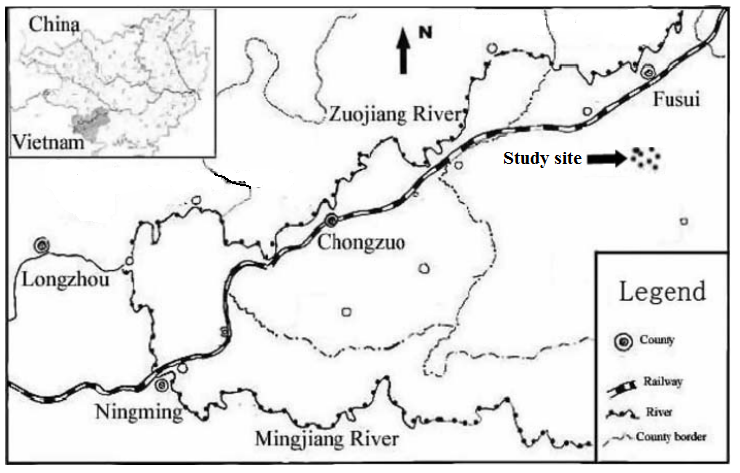


Figure 1.

Figure 2.

Figure 3.

Figure 4.

Figure 5.

Figure 6.