

**Mycophagy among Japanese macaques in Yakushima: Fungal species diversity
and behavioral patterns**

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A short title: Mycophagy among Japanese macaques

ABSTRACT

Mycophagy (fungus-feeding) by Japanese macaques (*Macaca fuscata yakui*) in Yakushima has been observed by many researchers, but no detailed information is available on this behavior including which fungi species are consumed. To provide a general description of mycophagy and to understand how and whether macaques avoid poisonous fungi, we conducted behavioral observation of wild Japanese macaques in Yakushima and used molecular techniques to identify fungi species. The results indicate that the diet of the macaques contains a large variety of fungi species (67 possible species in 31 genera), although they compose a very small portion of the total diet composition (2.2% of the annual feeding time). Fungi which were eaten by macaques immediately after they picked up were less likely to be poisonous than those which were examined (sniffed, nibbled, carefully handled) by macaques. However, such examining behaviors did not appear to increase the macaques' abilities to detect poisonous fungi. Fungi that were only partially consumed included more poisonous species than those fully consumed with/without examining behavior yet this was not significant. Taste, therefore, might also play an important role in discriminating poisonous from non-poisonous.

Key words Japanese macaque; *Macaca fuscata yakui*; mycophagy; poisonous fungi; fungal diversity

35 INTRODUCTION

36 While mycophagy has been reported in at least 24 primate species (Hanson et
37 al. 2003; Hanya 2004; Hilário and Ferrari 2010), fungi have received less attention
38 compared with other food items. Fungi usually account for only a small part of the diet
39 composition of most primate species, such as mountain gorillas, bonobos, green
40 monkeys, and Japanese macaques (Harrison 1984; Watts 1984; Bermejo et al. 1995;
41 Hill 1997). According to Hanya (2004), Japanese macaques in the high-altitude
42 coniferous forest of Yakushima, where fruits are less abundant, eat fungi more often
43 than their lowland counterparts. However, no data show whether they feed on specific
44 fungal species.

45 A few primates are known to consume large quantities of fungi on a regular
46 basis, for example Goeldi's monkeys and buffy-headed marmosets (Hilário and Ferrari
47 2010; Porter 2001). Goeldi's monkeys who mainly consumed fungi that were
48 predominantly fiber (68 – 83%) have molars with high shearing crests, which might
49 increase their ability to shred fungi into small pieces and thus promote digestion (Porter
50 and Garber 2004; Hanson et al. 2006). Another elucidation for intense mycophagy
51 among Goeldi's monkeys is as an effective tactic to lower the chance of interspecific
52 competition for fruits with large animals (Porter 2001).

53 One problem that studies on mycophagy face is fungal species identification.
54 Morphology-based identification is challenging because fungi are quite variable in
55 appearance and many cryptic species exist, as evidenced by the fact that humans around
56 the world occasionally misidentify fungi and are poisoned as a result (Eren et al. 2010;
57 Ishihara and Yamaura 1992; Unluoglu and Tayfur 2003). In this study, we applied
58 DNA-based species identification, which requires no expertise in mycology. Moreover,

59 this method allows us to identify the species even from debris that an animal left behind.

60 Since we do not have to collect intact fruiting bodies to obtain macroscopic and
61 microscopic traits, it is particularly effective in studies on mycophagy by wild animals.

62 Wild Japanese macaques of Yakushima are an ideal study species for
63 mycophagy because researchers have repeatedly observed them eating fungi (Agetsuma
64 and Noma 1995; Hill 1997; Hanya 2004) and they are well habituated and can be
65 observed from a close distance. Besides, the fungal diversity is high in Yakushima
66 (Tsujino et al. 2009) and many genome sequences of fungi collected there have been
67 added to GenBank, the NIH genetic sequence database
68 (<http://www.ncbi.nlm.nih.gov/genbank/>), over the past several years. Since DNA-based
69 species identification is a matching process, we can expect reliable results with a large
70 database.

71 The purposes of this study were (1) to provide a general description of
72 mycophagy among wild Japanese macaques in Yakushima, and (2) to elucidate whether
73 and how macaques avoid poisonous fungi. For the first study purpose, we estimated the
74 diet composition and determined whether the macaques consume a wide variety of
75 fungi. For the second purpose, we focused on detailed mycophagy behaviors, which
76 may reveal whether macaques avoid specific species, namely ‘poisonous mushrooms’.
77 Sherratt et al. (2005) indicated that fungi species that are poisonous to humans are more
78 likely to exhibit an unpleasant odor, as judged by humans. Such poisonous species may
79 have a particular taste as it is possibly associated with the odor (Sherratt et al. 2005).
80 Macaques may decide whether to eat the fungi or not based on on-site assessment of
81 such chemical ‘warning’ signals. Alternatively, macaques may have previous
82 knowledge about fungi species that are edible to them, as they do about plant food

items. In order to confirm these two possibilities, we established a set of predictions suggesting that the fungi that macaques did not feed on would be more likely to be poisonous compared with those eaten. Additionally, we provide information on the fungi that macaques consumed repeatedly to explore the possibility of their knowledge about fungi species through previous feeding experiences.

METHODS

All data collection was non-invasive and permitted by the Yakushima Forest Environment Conservation Center and Kagoshima Prefectural Government. The research adhered to the guidelines established by the Field Research Committee of the Primate Research Institute, Kyoto University ('Guidelines for Studying Wild Primates or Using Wild Primates in Research'), and the legal requirements in Japan.

Study Site and Animals

Yakushima is a mountainous island located in the southwestern part of Japan (30°N, 130°E) with an area of 505 km². Our study site, Hanyama, is part of the Yakushima National Park and is located in the western coastal area of Yakushima (Fig. 1). The study area is covered by subtropical/warm-temperate, evergreen broad-leaved vegetation (Yamagiwa 2008). The mean annual temperature and rainfall (from August 2009 to July 2010) were 20.3°C and 3,223.7 mm. The meteorological data were collected at the Yakushima Field Station of Kyoto University in Nagata, which is approximately 8 km from the study site (Shin-ichiro Aiba, unpublished data). The main study subjects were nine adult females of the AT troop, which consists of seven adult males and thirteen juveniles (1–4 years old). They were individually identified by

physical features. There is no natural predator of wild Japanese macaques in Yakushima, and the macaques are well habituated but not provisioned.

Data Collection

The study period was from August 2009 to September 2010. We collected the data by focal animal sampling, where we recorded the activity and food item of the focal animal with a 1-min interval to estimate the proportion of mycophagy in the total feeding time. We also calculated annual and monthly diet composition based on this data. For detailed data analysis on mycophagy, we continuously recorded the onset and end of all feeding events (see definition and Table 1). We used all-occurrence sampling of mycophagy and recorded the duration of the feeding/foraging bout. We also collected data on mycophagy by non-focal individuals whenever possible. We used this all-occurrence sampling of focal animals and data for non-focal animals to compile a list of the fungi that macaques consumed and to make a detailed analysis of their mycophagy behavior. Macaques ate fungi off the ground, from decaying logs, or on the trunk of living trees. As fungi have brittle flesh, macaques often dropped small fragments even when they completely consumed the whole fruiting bodies. We collected such fungal samples when available except for cases when macaques did not leave any debris. After coming back to the field station, we placed a small section of each fruiting body sample in 99.5% ethanol.

We changed focal animals every 180 min with the intention of collecting data from several individuals during a single day. When we lost the focal animal and failed to resume observation within 20 min, we started a new session with a different individual. Here we present the data on the frequency and proportion of mycophagy

related to feeding time that we collected over 223 sessions, amounting to 669 hours in total. We categorized all of the food items eaten by the focal animals as follows: fungi, other fungal materials, seeds, fruits, flowers, leaves, shoots, bark/branches, insects, and others. The category “other fungal materials” refers to the white mycelium found frequently under the bark of dead trees. Leaves include both mature and young leaves. Others consist of herbaceous plants, soil, water, and unidentified items. We calculated monthly dietary composition from a 1-min instantaneous recording of feeding events of the focal animal as the proportion of each food item to the total feeding time. We levelled off August and September, months that data were collected during two calendar years, and calculated annual dietary composition as the average for the 12 months.

Definitions for Mycophagy Behavior

We defined one *foraging event* as a period starting when a macaque picked up a fungus and ending when the animal finished handling it. While foraging for fungi, macaques sometimes showed additional conspicuous behaviors such as sniffing, nibbling (no spitting out), and careful handling (splitting a fungi into several pieces; rubbing a fungus with the hands). We defined that macaques *examined* fungi when they showed at least one of these behaviors.

When a macaque entered within a radius of 1 m from a fungus, we regarded this as the animal encountering the fungus. We divided behavioral sequences of mycophagy into the following four phases: when a macaque (i) encountered, (ii) picked up, (iii) examined, and (iv) consumed a fungus. At each phase, the macaque chose either of the following two behavioral options: (i) picked up or did not pick up, (ii) examined or did not examine, (iii) ate or did not eat, and (iv) consumed a whole piece of fungus or

ate it only partially. Using these sequences, we classified behavioral patterns into six categories (Table 1):

Foraging includes the events during which macaques handle fungi, thus consisting of RE, EX-A, EX-P, NE-A, and NE-P. *Feeding* represents situations when the macaque actually consumes a fungus, thus including EX-A, EX-P, NE-A, and NE-P.

Prediction of Proportion of Poisonous Fungi

We predicted that fungi that macaques did not eat were more likely to be poisonous if macaques avoided them. We, therefore, compared the proportion of poisonous fungi between the two choices at each phase.

At Phase i, where macaques encountered fungi, the proportion of poisonous species is expected to be higher in fungi that were left untouched (IG) than in those that were picked up (RE + EX-A + EX-P + NE-A + NE-P). At this phase, macaques did not have any physical contact with the fungi. Therefore, they would discriminate poisonous fungi by judging them from knowledge they had acquired through previous feeding experiences.

At Phase ii, where macaques picked up fungi, the proportion of poisonous species is expected to be higher in the fungi examined than in those immediately eaten by macaques (RE + EX-A + EX-P > NE-A + NE-P). This suggests macaques would discriminate poisonous fungi based on previous knowledge.

At Phase iii, where macaques examined fungi, the proportion of poisonous species is expected to be higher in fungi rejected than in those eaten by macaques (RE + EX-A + EX-P). This suggests that macaques would discriminate poisonous fungi by examining behaviors.

At Phase iv, where macaques consumed fungi, the proportion of poisonous species is expected to be higher in fungi that were partially eaten than in those completely eaten by macaques (EX-P > EX-A; NE-P > NE-A). Since macaques ingest a few bites of the fungi before making a decision, this suggests that they would screen out poisonous fungi by taste.

We used Fisher's exact tests to compare the proportion of poisonous fungi at each phase using the free statistical package R (version 2.13.2).

DNA Extraction, PCR Amplification, and Sequencing

We extracted total DNA from each fruiting body sample following a modified method described in Sato and Murakami (2008). We added 300 μ L CTAB buffer to the crushed fungal tissue. After incubating at 55°C for 30 min, we added 300 μ L CIA (chloroform-isoamyl alcohol; 24:1 [vol/vol]) to the mixture and centrifuged it for 15 min at 4,200 rpm. We transferred 100 μ L clear supernatant to a new microtube, and then with 100 μ L isopropanol added we centrifuged the mixture for 30 min at 4,200 rpm. After washing with 70% ethanol, we dissolved the precipitated DNA in a 50 μ L TE buffer. We amplified Internal transcribed spacer 2 (ITS2) regions from nuclear ribosomal DNA using the ITS3 and ITS4 primers described by White et al. (1990). We carried out PCR amplification using 1 μ L total DNA in a 20- μ L reaction mixture containing Ampdirect Plus (Shimadzu, Kyoto, Japan), 10 pmol of both forward and reverse primers, and 0.5 units of BIOTAQ HS DNA Polymerase (Shimadzu, Kyoto, Japan). Cycling parameters for PCR were as follows: we conducted denaturation at 95°C for 10 min, followed by 40 cycles at 94°C for 30 s, 58°C for 30 s, and 72°C for 30 s, and followed by a final extension of 2 min at 72°C. We added 5 μ L of 0.05 $\times$ ExoSAP-

IT (USB Corp., Cleveland, Ohio) to the PCR products for purification. We incubated the PCR products at 37 °C for 15 min and then deactivated the enzymes at 80°C for 15 min. We sequenced the purified PCR products using the same primers used for amplification. We performed nucleotide sequencing using an ABI 3130 Genetic Analyzer (Applied Biosystems, Foster City, California USA) with BigDye-Terminator v3.1 (Applied Biosystems), following the manufacturer's protocols.

Fungal Species Identification

We compared the nucleotide sequences obtained with the sequences complied in the NCBI GenBank database. To establish the list of fungi species that the macaques interacted with or ignored, we included the genetic sequences of fungi that were consumed by both focal and non-focal animals as we collected data by all-occurrence sampling. For each sample, we chose the species with the highest bit score when max identity was 97% or over. Among 478 fungal samples we collected, we successfully obtained the genetic sequences from 398 samples and identified 235 samples to the species level. For credibility of species identification, we did not provide the species name for those with max identity lower than 97% (82% for the lowest) but treated them as *sp.* and used them only for analysis at the genus level. The five most possible candidates suggested by a BLAST search were of the same genus at the rate of 86% or belonged to one of the genera that were already in our list. Therefore, we believe that we have provided a fairly accurate estimate of the number of fungus genera.

Toxicity of Fungi

We divided fungi into two groups, poisonous and non-poisonous, based on information from a reference book (Imazeki et al. 1988). We admit that the information on toxicity in the reference books is specific to humans. Due to the similarities in digestive systems between a Japanese macaque and a human, such as the lack of a foregut fermentation system, we assumed that fungi poisonous to humans are also poisonous to macaques.

RESULTS

General Features of Mycophagy

During the observation, all the focal animals consumed fungi. Mycophagy accounted for only 2.2% of the total feeding time of Japanese macaques over the study period, whereas fruits, leaves, and seeds constituted substantial portions of it (42.6%, 18.1%, and 11.4%, respectively). There were seasonal changes in their monthly dietary composition (Fig. 2). Frequency of mycophagy reached its highest during May–August, when the macaques mainly fed on fleshy fruits (*Myrica rubra*) (Table 2). Macaques rarely ate fungi between September and January.

Mycophagy was associated with the feeding time of other fungal materials, fruits and others (other fungal materials: $r = 0.58$, $P < 0.05$, fruits: $r = 0.83$, $P < 0.001$, others: $r = 0.7$, $P < 0.05$). There was no such correlation between mycophagy and the consumption of other food items (seeds: $r = -0.51$, $P = 0.09$, flowers: $r = 0.52$, $P = 0.08$, leaves: $r = 0.55$, $P = 0.06$, shoots: $r = 0.45$, $P = 0.14$, bark/branches: $r = -0.01$, $P = 0.97$, insects: $r = -0.2$, $P = 0.54$).

The total numbers of fungi species and genera that the macaques actually consumed (at least partially) were 67 and 31, respectively (Table 3, Appendix).

Eighteen species (18 genera) were ignored by macaques and 25 species (11 genera) were rejected. Among these 110 species (51 genera), 40 species (23 genera) are described in the reference book (Imazeki et al. 1988). The number of fungi ignored by macaques is underestimated because, by definition, fungi were supposed to be large enough to be found with the naked eye. Furthermore, considering that all of the fungi we recorded were located less than 1-m away from macaques, it was unlikely that neither macaques nor the observers missed many fungi. Therefore, we assume that those fungi were left untouched because the macaques were not interested in them, rather than simply overlooking them.

Behavioral Patterns

Japanese macaques generally consumed fungi without examining behaviors (Table 2). The proportion of poisonous fungi species in the total number of fungi they picked up was not significantly different from that in the total number of fungi they ignored. (Phase i: $P = 1$, Fig. 3). The proportion of poisonous species was significantly higher among the fungi examined by the macaques compared with the fungi they ate immediately (Phase ii: $P < 0.0001$). However, when they exhibited examining behaviors, the proportion of poisonous species did not differ between the rejected fungi and the eaten fungi (Phase iii: $P = 1$). A marginally significant trend was found in fungi that were completely consumed compared with those only partially eaten by macaques with examining behaviors (Phase iv: $P = 0.086$). The same pattern was found when they did not exhibit examining behaviors while eating, yet this difference was also marginally significant (Phase iv: $P = 0.074$).

To clarify behavioral consistency for a particular fungi species, we analyzed repeated consumption of the same species. We pooled behavioral patterns for each species, and thus no individual difference is mentioned here. When the macaques encountered the same species multiple times, they tended to show similar behavioral patterns. For example, when they encountered the same species twice (18 species), the proportion showing the same behavioral pattern was 61%, which was much higher than the chance level (1/6) ($P < 0.0001$, binomial test). The same was true for fungi eaten three times (25% of eight species, $P = 0.019$) and four times (25% of five species, $P = 0.023$). The same pattern was not found for species eaten more than four times (five times: 0% of three species, $P = 1$; six times: 0% of six species, $P = 1$; nine times: 0% of one species, $P = 1$; 27 times: one species, $P = 1$). When combining the six categories into two, based on whether the macaques consumed the fungus (NE-A, NE-P, EX-A, EX-P) or not (IG, RE), there was a stronger tendency for macaques to show the same response to the same species. The proportion of showing only either of the two behaviors became significantly higher than the chance level for the species the macaques encountered twice (15 out of 18 species, $P < 0.01$, binomial test), three times (five out of eight species, $P < 0.05$), five times (three out of three species, $P < 0.001$), six times (two out of six species, $P < 0.05$), nine times (one out of one species, $P < 0.005$), and 27 times (one out of one species, $P < 0.0001$). The only exception was the species encountered exactly four times, where there was no such tendency (two out of three species, $P = 0.12$).

DISCUSSION

General Features of Mycophagy among Japanese Macaques

297 Mycophagy among Japanese macaques in Yakushima comprises only a small
298 portion of feeding time, which might be explained by their relatively large body size
299 compared with other intensively mycophagous primates. Mycophagy by the macaques
300 constituted only 2.2% of the annual feeding time and 4.5% during the peak month
301 (June). These findings correspond to general patterns in mycophagy among primates,
302 where fungi are generally not important food resources (Hanson et al. 2003). For
303 example, fungi account for 1.2% of the annual feeding time in green monkeys, 0.2% in
304 mountain gorillas, and 1.7% in bonobos (Bermejo et al. 1995; Harrison 1984; Watts
305 1984). On the other hand, Goeldi's monkeys and buffy-headed marmosets are
306 exceptionally strong mycophagous primates. The average feeding time on fungi by
307 Goeldi's monkeys is 31%, which reaches 65% during the peak month (Porter 2001), and
308 that by buffy-headed marmosets is 64.8% and 70.2%, respectively (Hilário and Ferrari
309 2010). These animals are much smaller (Goeldi's monkeys: 400-535 g, buffy-headed
310 marmosets: 406 g) compared with other primates known to eat fungi, such as gorillas
311 (97.9–159.2 kg), bonobos (31.0–39.0 kg), and vervet monkeys (3.3–4.6 kg) (Rowe and
312 Mittermeier 1996). Patchy distribution and the smaller food-patch size of fungi make it
313 difficult for them to be the main or fallback food resources for larger animals.
314 Interestingly, there is also a relationship between mycophagy and body size among
315 marsupials, where large species tend to become less mycophagous (Johnson 1996).
316 Considering the fact that Japanese macaques (8.3–18.0 kg) are larger than most of those
317 small mycophagous primates and marsupials, their low mycophagy frequency appears
318 to be consistent with this pattern. The fact that fungi constituted 14% of the diet of
319 Japanese macaques in a harsh environment with lower fruit availability (Hanya 2004)
320 indicates that environmental factors also contribute to mycophagy frequency. Fungi are

321 nonetheless still not as important to those macaques as they are to small mycophagous
322 animals.

323 There was a positive correlation between the consumption of fungal fruiting
324 bodies and fungal materials. This consistency may reflect fungal emergence patterns as
325 both are categorized as fungi. Previous studies showed that fungal fruiting emergence in
326 evergreen broad-leaved forests in Japan is a seasonal event that is affected by
327 temperature and rainfall (Tsujino et al. 2009; Murakami 1989). Mycophagy was also
328 associated with the feeding time of fruits. Macaques consumed fungi most often during
329 May–August while their main food items were fleshy fruits of *M. rubra*. *M. rubra* fruits
330 are highly preferred by Japanese macaques (Agetsuma and Noma 1995), and they
331 reached up to 60% of their diet during the peak month in this study. Fungi therefore are
332 not a fallback food, which is defined as a food eaten during times when preferred foods
333 are scarce. During the research period, we observed macaques fighting over a fungus at
334 least twenty times. These findings suggest the notion that fungi are valuable foods for
335 macaques. The high protein values of some fungi (Agrahar-Murugkar and
336 Subbulakshmi 2005) might be related to this tendency, while simple-stomach macaques
337 without strong fermentation system may not readily derive such proteins from fungi
338 (Hanson et al. 2006). Since the nutritional quality varies among fungi species, further
339 analysis of the nutritional values of fungi might help us to understand why macaques
340 desire fungi.

341 Japanese macaques in Yakushima consumed an enormous variety of fungi
342 (possibly 67 species of 31 genera). This could rise further if fungal samples were
343 available from all mycophagy events. Yet, the numbers are still astonishing compared
344 with other mycophagous primates such as Goeldi's monkeys, which consume only four

species (Hanson et al. 2003). Even northern flying squirrels, primarily mycophagous mammals, feed on fungi of only 23 genera (Lehmkuhl et al. 2004). This fact indicates that Japanese macaques interact with more species of fungi via mycophagy than do frequent mycophagous mammals. Why do Japanese macaques consume such a diversity of fungi? Since the macaques move/feed both on the ground and in the trees, they have more chances to find fungi compared to highly arboreal species. Diversified mycophagy among macaques might also reflect the high fungal diversity in Yakushima (Tsujino et al. 2009). Our reasoning is based on the assumption that macaques are opportunistic when eating fungi rather than being selective mycophagists. In fact, when macaques encounter a fungus, they usually ingest it without exhibiting examining behaviors, although they also exhibit avoidance of poisonous fungi to some degree (see below). Since few sites have accumulated a body of data on fungus availability in regard to species diversity comparable to that in Yakushima (Tsujino et al. 2009), further studies are needed before drawing concrete conclusions.

Behavioral Patterns: Exclusion of Poisonous Fungi

Our findings indicate the possibility that Japanese macaques can discriminate poisonous fungi effectively at two different phases: first when they hold the fungi in their hands (Phase ii), and then when they actually take a few bites (Phase iv). Therefore, macaques seemed to use mixed tactics to avoid poisonous fungi based on both previous knowledge and on-site assessment of taste, and neither alone was sufficient to discriminate poisonous fungi perfectly.

When the macaques picked up fungi, they generally did not exhibit examining behaviors but immediately started eating them. In most cases, such fungi were found to

be non-poisonous. However, the fungi examined by the macaques were more likely to be poisonous than those eaten immediately. These findings suggest the possibility that macaques visually discern poisonous fungi based on knowledge they have acquired through previous feeding experiences.

There were nine cases of the macaques eating poisonous fungi after showing examining behaviors, indicating that poisonous fungi were not always excluded at the first phase. At the second phase, the rest of the poisonous fungi were screened out except for one case. The macaques are likely to screen out poisonous fungi by actually taking a few bites on the spot, possibly judging from the taste and smell. We failed to find statistical significance for this finding because most of the poisonous fungi had already been excluded at the first phase.

Macaques did not selectively pick up non-poisonous fungi off the ground or from the trees and decaying logs (Phase i). It appears that examining behaviors were not useful for eliminating poisonous fungi (Phase iii). Examination of bibliographic descriptions of fungi in North America and Europe reveal that poisonous species are more likely to emit distinctive odors, which might have evolved as warning odors to enhance avoidance learning by mycophagists (Sherratt et al. 2005). Our research shows that macaques cannot perceive such warning odors. Therefore, warning odors emanating from poisonous fungi do not function as a deterrent to mycophagy for Japanese macaques.

Behavioral Consistency and Possibility of Group Learning

Macaques tended to display the same foraging behavior for the same fungus species. This consistent behavior can be explained on two different levels, at the

individual or among-group level. For example, there were some cases where the same individual consumed a particular fungus repeatedly. Among the nine individuals who ate *Crepidotus mollis*, the most frequently eaten species, all the nine animals showed the same tendency as to whether they ate or did not eat. In a detailed evaluation with six categories, seven individuals consumed it more than twice and four of them always showed the same behavior (NE-A). Although there were some consistencies as we suggested, their behavioral patterns were not universal and hence we should admit other interpretations. Macaques may make on-site assessments of fungi on a case-by-case basis rather than depending on unequivocal cues.

In this study, we have shown that Japanese macaques may have a certain degree of knowledge about poisonous fungi species. This finding would lead us to a legitimate question about the possible process of knowledge acquisition and how and whether macaques would share such information. There were cases where mothers joining their offspring in eating fungi, and vice versa. We also observed a 1-year-old male, who was watching his mother eating a fungus, got a piece left by his mother. We could not obtain enough evidence to evaluate their memory or learning performance. However, these instances imply possibilities for group learning, which is crucial, especially for immatures. A study on red squirrels suggests that naive animals, who have not yet learned what not to eat, may fail to avoid poisonous fungi (Camazine et al. 1983). Further research to explore how young animals acquire knowledge about fungi may reveal the mechanism of group learning.

In conclusion, Japanese macaques in Yakushima consume a large variety of fungi, and mycophagy occurs with fungal fruiting. They eat a fungus when available,

417 yet it is an act of minor importance from a quantitative viewpoint. When macaques
418 ingest a fungal fruiting body immediately without showing examining behaviors, it is
419 highly unlikely to be poisonous. Macaques therefore might have knowledge of the fungi
420 that are edible to them. They eliminate poisonous fungi by taste, while examining
421 behaviors do not function effectively to exclude poisonous species. Behavioral
422 consistency observed in repeated eating of certain species also indicates that the
423 macaques might share common knowledge of some fungi species as food resources.
424

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Table 1: Definition of mycophagy by Japanese macaques

Behavioral categories	Definitions
Ignore (IG)	Not touching a mushroom that was found within a 1-m radius of the animal *
Reject (RE)	Examining a mushroom but not eating it. Might take a bite but spit it out (no ingestion)
Examine, eat all (EX-A)	Showing examining behaviors while/before consuming the whole mushroom
Examine, eat partially (EX-P)	Same as Ex-A except for mushroom consumption is only partially
Not examine, eat all (NE-A)	Consuming the whole mushroom without examining behaviors
Not examine, eat partially (NE-P)	No examining behavior observed while ingesting a mushroom. Only a part of the mushroom or some of the multiple mushrooms available are ingested

* Note that the number mushrooms may be underestimated by the observer's oversight

Table 2: Observation time and the number of mycophagy events of each behavioral category

Month		Behavioral observation (hour)		Number of mycophagy events						Total
				IG	RE	EX-A	EX-P	NE-A	NE-P	
2009	Aug		12	0	1	1	0	15	3	20
	Sep		21	0	0	0	0	0	0	0
	Oct		51	0	0	0	0	1	0	1
	Nov		57	0	1	0	0	1	2	4
	Dec		42	0	0	2	1	3	0	6
2010	Jan		45	0	0	0	0	0	0	0
	Feb		27	0	1	0	0	5	1	7
	Mar		39	0	0	2	0	15	0	17
	Apr		111	0	0	1	0	34	3	38
	May		99	2	6	4	1	78	17	108
	Jun		45	3	5	4	5	44	3	64
	Jul		36	2	2	0	1	23	3	31
	Aug		57	0	0	3	0	22	3	28
	Sep		27	0	0	0	0	2	2	4
	Total		669	7	16	17	8	243	37	328

All the data presented here was collected by focal observation on adult female macaques. Data include the cases where fungal samples were failed to be collected

Table 3: Number of fungal samples, genera and species identified under each behavioral category

Behavior		All samples		Identified		
Category	Description	Sample	Genus	Sample	Genus	Species
IG	Ignore (no touch)	36	27	26	24	24
RE	Examine, not eat	53	22	37	12	34
NE-A	Not examine, eat all	210	33	116	24	51
NE-P	Not examine, eat partially	57	23	37	19	26
EX-A	Examine, eat all	19	9	9	6	7
EX-P	Examine, eat partially	17	5	10	4	7
Total number of samples		392 (25)	-	235 (18)	-	-
Genera or species foraged or ingored *		-	66 (5)	-	51 (3)	110 (7)
Genera or species consumed **		-	41 (4)	-	31 (3)	67 (6)

Data were collected by all-occurrence sampling on both focal and non-focal animals

Samples with the maximum identify $\geq 97\%$ were defined as identified

* Includes all the 6 behavioral categories (IG, RE, NE-A, NE-P, EX-A, EX-P)

** Either whole (NE-A, EX-A) or partial (NE-P, EX-P) consumption was observed. Numbers in parentheses are those only family, order, or class were available

Figure legends

Figure 1: Home range of AT troop in the study area, on the western coastal area of Yakushima, Kagoshima Prefecture, Japan, estimated by the minimum convex polygon (MCP).

Figure 2: Seasonal variations in dietary composition (August 2009 – September 2010)

Figure 3: Proportion of poisonous mushrooms among each mycophagy behaviors. The number of samples collected is shown in each bar. IG, ignore; NE-A, not examine and eat all; NE-P, not examine and eat partially; RE, reject; EX-A; examine and eat all; EX-P, examine and eat partially (see Table 1 for detailed behavioral description)

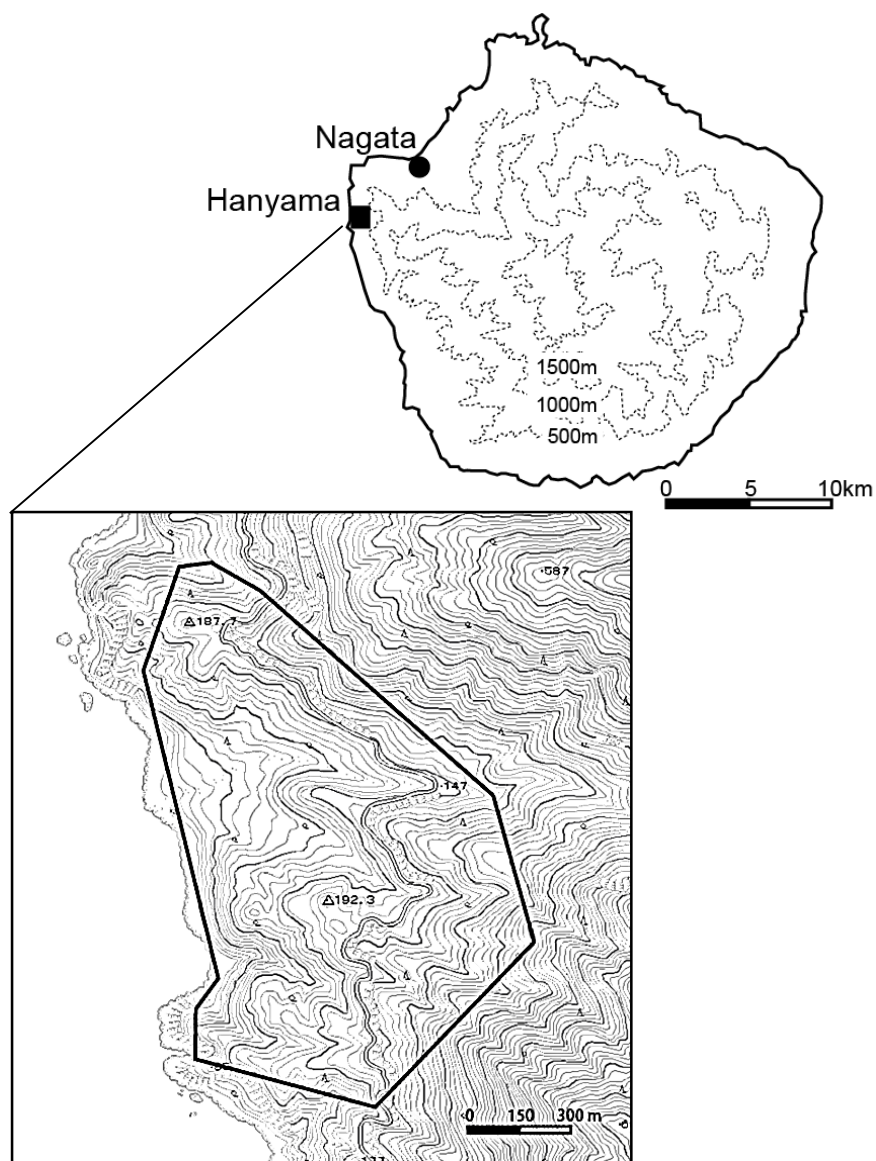


Figure 1

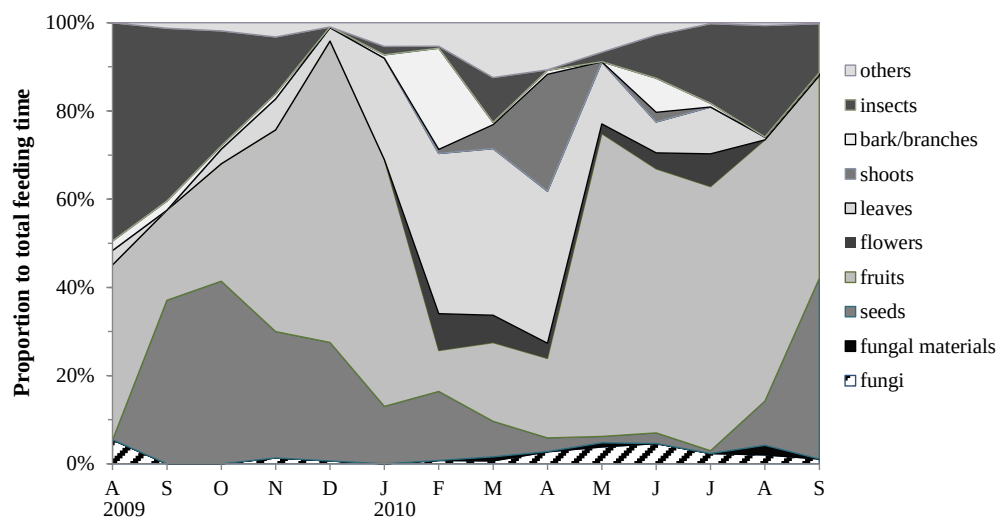


Figure 2

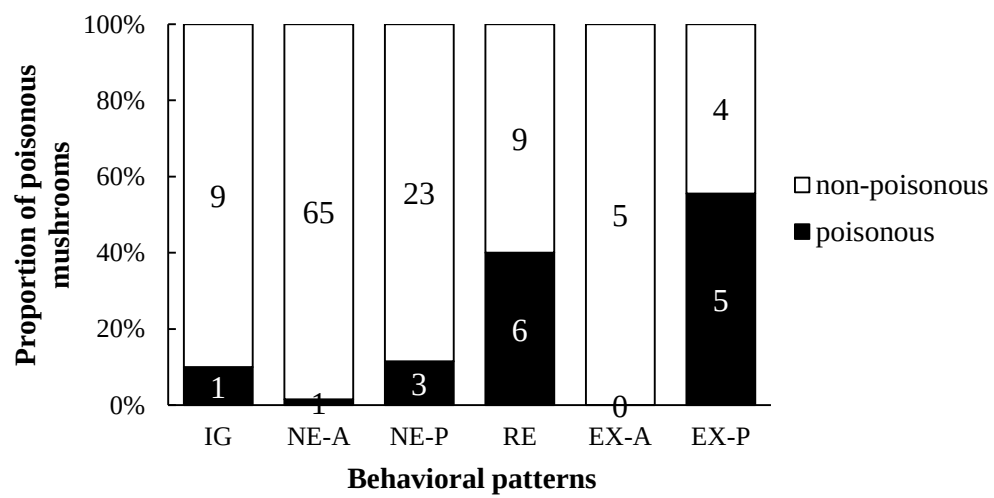


Figure 3

Appendix. List of mushroom species foraged or ignored by Japanese macaques in Yakushima

Species	Edibility/ toxicity	Behavioral category							Sampling																		
		IG	RE	NE-A	NE-P	EX-A	EX-P	Total	2009												2010						
									7	8	9	10	11	12	1	2	3	4	5	6	7	8	9				
<i>Agaricus moelleri</i>			1					1			○																
<i>Agaricus nivescens</i>	NA	1						1	○																		
<i>Agaricus subrutescens</i>	Edible		2					2	○										○								
<i>Agrocybe aegerita</i>			1					1												○							
<i>Agrocybe chaxingu</i>			1	1				2	○											○							
<i>Agrocybe cylindracea</i>	Edible			1	4			5		○		○	○						○	○							
<i>Amanita alboflavescentis</i>				1				1																		○	
<i>Amanita esculenta</i>	NA			1				1								○	○										
<i>Amanita fritillaria</i>						1		1												○							
<i>Amanita griseoverrucosa</i>			1					1		○																	
<i>Amanita imazekii</i>			1					1		○																	
<i>Amanita orientigemmata</i>			1					1	○																		
<i>Amanita pseudoporphyria</i>	Poisonous		2				1	3	○	○																	
<i>Amanita sepiacea</i>	NA		1				1	2											○								
<i>Amanita solitaria</i>			1					1	○																		
<i>Amanita spissacea</i>	Poisonous		1		1		4	6	○											○							
<i>Amanita virgineoides</i>	NA		1					1																		○	
<i>Amanita sp. A</i>		1	1		1			3											○	○							
<i>Amanita sp. B</i>			1					1	○																		
<i>Amauroderma rugosum</i>					1			1												○							
<i>Armillaria mellea</i>					1			1						○													
<i>Auricularia aff. auricula-judae</i>	Edible			3				3												○			○	○			
<i>Auricularia auricula-judae</i>	Edible			4				4								○				○	○						
<i>Auricularia polytricha</i>	Edible			8	1			9		○						○		○	○								
<i>Boletus fraternus</i>				1				1												○							

Species	Edibility/ toxicity	Behavioral category							Total	Sampling													
		IG	RE	NE-A	NE-P	EX-A	EX-P	2009								2010							
									7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
<i>Campanella alba</i>			1					1											○				
<i>Chaetocalathus galeatus</i>		1						1									○						
<i>Collybia confluens</i>		1						1												○			
<i>Collybia sp.</i>			1					1											○				
<i>Conocybe lactea</i>	NA		1					1														○	
<i>Coriolopsis strumosa</i>				2				2											○				
<i>Crepidotus mollis</i>	NA			22	4		1	27	○				○				○	○	○	○		○	
<i>Crepidotus sp.</i>				1				1											○				
<i>Cyptotrama asprata</i>		1						1											○				
<i>Dictyopanus gloeocystidiatus</i>		1						1												○			
<i>Entoloma sp.</i>				2			1	3	○										○				
<i>Filoboletus manipularis</i>	NA	2						2											○				
<i>Ganoderma mastoporum</i>		1						1	○														
<i>Gymnopilus crociphyllus</i>		1						1											○				
<i>Gymnopilus liquiritiae</i>	NA			2	1			3											○				
<i>Hericium coralloides</i>			1					1											○				
<i>Hohenbuehelia sp.</i>				1				1												○			
<i>Hygrocybe reidii</i>		1						1										○					
<i>Hypholoma fasciculare</i>	Poisonous			1	1			2	○													○	
<i>Inocybe sphaerospora</i>	NA	1						1													○		
<i>Lactarius furcatus</i>			1					1	○														
<i>Lactarius gerardii</i>	NA		1					1													○		
<i>Leccinum sp.</i>				2				2													○	○	
<i>Lentinula edodes</i>	Edible				1			1				○											
<i>Lenzites elegans</i>		1						1									○						
Marasmiaceae sp. A *				4	1			5										○		○		○	
Marasmiaceae sp. B *		1						1											○				

Species	Edibility/ toxicity	Behavioral category							Total	Sampling																		
		IG	RE	NE-A	NE-P	EX-A	EX-P	2009									2010											
									7	8	9	10	11	12	1	2	3	4	5	6	7	8	9					
<i>Russula pectinatoides</i>	NA		1					1											○									
<i>Russula vesca</i>	NA			1			1	2	○	○																		
<i>Russula sp. A</i>			1					1	○																			
<i>Russula sp. B</i>				2				2								○	○											
<i>Russula sp. C</i>			1					1	○																			
<i>Russula sp. D</i>					1			1															○					
<i>Russula sp. E</i>			1	3				4												○				○				
<i>Russula sp. F</i>			1					1	○																			
<i>Russula sp. G</i>			1	1	1	1		4	○										○									
<i>Russula sp. H</i>			1					1													○							
<i>Russula sp. I</i>				1				1											○									
<i>Russula sp. J</i>				1	2			3	○														○					
<i>Russula sp. K</i>				1				1													○							
<i>Russula sp. L</i>				1				1											○									
<i>Russula sp. M</i>				1				1												○								
<i>Russula sp. N</i>			1					1	○																			
Russulaceae sp. A *				2				2											○									
Russulaceae sp. B *		1		5				6	○										○									
Russulaceae sp. C *				1				1		○																		
Russulaceae sp. D *				2				2										○	○									
<i>Schizophyllum commune</i>				3				3								○		○	○									
<i>Simocybe serrulate</i>		1						1											○									
<i>Stereum ostrea</i>	NA			3	2			5										○	○	○								
<i>Strobilomyces seminudes</i>	NA	1			1			2												○	○							
<i>Trichaptum biforme</i>	NA	2						2										○	○									
<i>Tylopilus ballouii</i>				1				1															○					
<i>Tylopilus sp.</i>				1				1												○								

Species	Edibility/ toxicity	Behavioral category							Total	Sampling																		
		IG	RE	NE-A	NE-P	EX-A	EX-P	2009						2010														
									7	8	9	10	11	12	1	2	3	4	5	6	7	8	9					
<i>Xerocomus chrysenteron</i>	Edible			1	1			2											○									
<i>Xerocomus subtomentosus</i>				1				1														○						
<i>Xerocomus sp.</i>		1						1													○							
<i>Zelleromyces sp.</i>		1						1									○											

Numbers in behavioral categories indicate the number of mycophagy events where mushroom samples were available. * = mushrooms identified only to the family level. NA = no information on edibility/toxicity provided by the reference book. Blank = species not addressed under the reference book.