A Unique Mutualism: Seed Dispersal and Primate Self-Medication

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Abstract
This paper reviews research conducted on various species of primates who utilize seed and leaf-swallowing strategies as effective mechanisms for self-medication, specifically parasite removal. Interestingly, while these primates rely on such self-medication processes for survival, the reproductive success of various plants is dependent on the dispersal of their seeds by such primates. Here, an unexpected mutualism is established. The implications of this ecological relationship on both organisms are assessed and the extent to which this mutualism is found is also discussed.

Introduction

The ongoing search for the cures to many of the ailments and diseases facing humans may be aided by some of our closest living relatives. As laboratory-made drugs fail to provide cures, there has been a move toward looking to plants and fungi in the hope of finding nature's remedy tucked away, possibly, in the understory of a South American rainforest. Humans are resorting back to their roots when technology ceases to be a cure-all. Perhaps looking back to our genetic relatives, the primates, and observing their use of the natural resources native to their habitats may one day provide the answers we seek. Primates have discovered two simple, yet effective methods of ridding themselves of life-threatening parasites. Through the simple use of leaves and seeds, primates all over the world are escaping death at the hand of a microscopic organism. Primates swallow leaves and void seeds as mechanisms of self-medication for intestinal parasites. Through these methods they have created a mutualism with flowering plants as an effective and reliable seed dispersal agent.

Primates are found across the globe and in various different habitats. The primates observed for the purpose of learning more about self-medication processes were studied in the field at ten different locations ranging from South America to Africa; however, they are most commonly found in tropical rainforests (Marcus 2002). The primate diet consists mostly of leaves, insects, and fruits. In tropical rainforests, primates make up 25-40% of the fruit-eating population (Kunz and Linsenmair, 2007).

Plants are stationary, and thereby rely on various mechanisms of other organisms to disperse their seeds and in turn, reproduce. This is especially important in the rainforest, where there is so much competition for reproductive success. Because of these reproductive pressures, the quality of a plant's seed disperser becomes increasingly important (Marcus, 2002). Many trees, especially flowering species, rely on large vertebrates to do this job by providing food for primates in hope that the seeds will be excreted, and unharmed, a certain distance away from the parent tree (Holbrook and Loiselle, 2009).

Leaf-swallowing sounds as if it would be a fairly simple, and meaningless process, but for primates, this habit could often mean life or death. This practice has been studied by several researchers who are looking at various species of primates found on three different continents, as well as an even larger number of plants who have given up their leaves as a life-saving remedy. Fowler, et al. (2007), studied the chimp species, *Pantroglodytes vellerosus,* at Gashaka Gumti National Park in eastern Nigeria. They tested 299 tested fecal samples, which yielded unchewed leaves in 3.7% of the samples. All unchewed samples were collected during the rainy season, which coincides with the season in which parasite infection is at its highest. In two of the samples with undigested herbaceous leaves, two small parasitic worms were found on the outer surface of the leaves in the fecal material. The most common plant species swallowed by the primates was *Desmodium gangeticum*. These leaves have a hairy surface with little variation in size and dimension among individual leaves (Fowler, et al., 2007). In vitro analysis of the chemicals found in similar species closely related to *D. gangeticum*, reveal that methanol extract and ethyl acetate present in these leaves is active on flagellate parasites and even killed the parasites at a concenentration of 500 mg/L (Négre, et al., 2006). Overall it was confirmed that chimpanzees do indeed digest leaves for medicinal purposes (Fowler, et al, 2007). This conclusion is consistent with a prior study that identified three other chimpanzee species that also engage in leaf-swallowing behavior for parasitic removal (Huffman and Canton, 2001). The leaves swallowed were not chewed, but rather excreted whole, which is evidence that the leaves are not used for food or nutritional value. Another piece of evidence supporting the leaf-swallowing theory is that nematode worms were discovered with the excreted *D. gangeticum* leaves. Additionally, this leaf-swallowing behavior occurred only during the rainy season, which coincides with the period of time in with the highest rate of parasitic infection (Fowler, et al., 2007).

It is evident that the leaf-swallowing phenomenon is indeed occurring, but research in this field has also been able to determine the likely mechanism and reasoning behind why this process is effective in expelling parasitic worms from the digestive tracts of primates. There are three important factors to how the leaf-swallowing process works. First, the timing of leaf-swallowing is crucial to achieve optimum results. Leaf-swallowing behavior usually occurs before the first meal of the day when the stomach and intestines are empty. Whole, unchewed leaves entering the empty stomach trigger an increased amount of motility and secretion of stomach acid. Stomach contractions during digestion cause the coarse surface of the leaves to come into contact with, and irritate, the lining of the stomach, which causes a mucus irritant to be created. This then promotes two protective effects: an increased secretion of acidic stomach juices and increased movement in contractions of the stomach and hindstomach which causes its contents to quickly be passed into the small intestine. The second factor is an increased rate in digestive "transit time", when compared to the time taken for seeds or other foods common to the chimpanzees' diet to pass through the excretory system. Finally, diarrhea, as a result of the presence of leaves in the feces, is also important because of the internal events that cause this state of fecal matter. Diarrhea occurs because of prolonged irritation of the digestive tract linings, as well as increased amounts of highly acidic gastric juices being excreted, which often causes water to be reabsorbed. Repeated leaf-swallowing behavior

* This author wrote the paper for Biology 133: Triopical Rainforests taught by Dr. Lynn Westley.

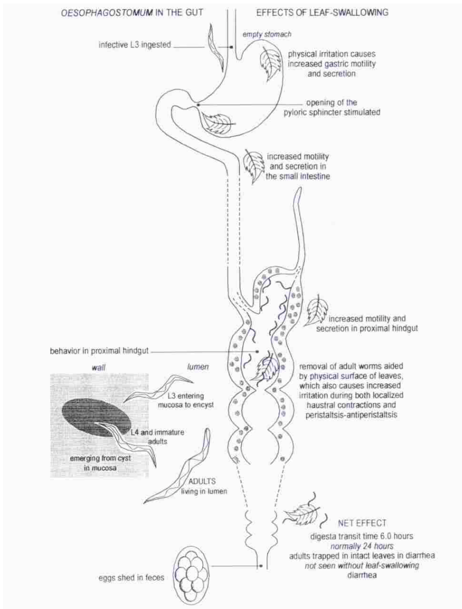

Figure 1: The proposed mechanism of leaf-swallowing and removal *of Oesophagostomum stephanostomum* from the digestive tract of primates (Huffman and Canton, 2001).

over the period in which parasitic infection is at its highest would result in decreasing the overall number of parasites present in the given individual. This behavior also functions in expelling the larvae of parasites, which would otherwise lead to a greater burden (Huffman and Canton, 2001). Figure 1 shows this process as proposed in a more concise form by Huffman and Canton (2001). This comes from their research on this specific process in Mahale chimpanzees and their use of the leaf-swallowing method to remove digestive parasites, specifically *Oesophagostomum stephanostomum*.

Another method used by primates is a process known as seed-swallowing or seed voiding. Garber andKitron (1997) studied the feeding behavior two species of tamarins. The first, were Panamanian, *Saguinus mystax*, tamarins observed in their natural habitat of secondary forest at Gatun Lake near Barro Colorado Island. The second species were moustached tamarins*, Saguinus geoffroyi*, found on Padre Isla near Iquitos, Peru. This study was one of the first to observe the seed-swallowing phenomenon in tamarins and thus provides a good basis for understanding the development of this unique method of self-medication. They found evidence that both the Panamanian and moustached species swallowed seeds from many different plants. However, the majority (86%) of these seeds came from three varieties*: Inga minutula, Annona acuminata*, and *Chrysophyllums* species, which were often digested along with the pulp. The combined weight of the seeds and pulp, on average, accounted for 2% of the tamarin's body weight. The dimensions (size, length, and width) of the seeds voided were similar for both *S. mystax* and *S. geoffrovi*. There are also noticeable differences in feeding behavior based on sex. For Panamanian tamarins*, Inga minutula* seeds voided were significantly ($p < 0.008$) longer and heavier ($p < 0.005$) in females than in males. Similarly, for moustached tamarins, *I. minutula* seeds were significantly longer in females than in males (Garber and Kitron, 1997). Seed voiding is an important process not only for these two species of tamarins, but for many species of primates to which these results can be applied.

This same seed-swallowing behavior is supported in work done by Kunz and Linsenmair (2007). They aimed to provide evidence that seed-swallowing is not species-specific, but rather a commonality amongst many primates. This study looked at *Papio anubis*, known more commonly as the olive baboon, which were studied in the field at Comoé National Park (CNP) in northern Ivory Coast, Africa. Kunz and Linsenmair (2007) also focused on specific feeding behaviors of the olive baboon. They found that the flowering tree*, Parkia biglobosa,* accounted for the majority of the baboons' diet. While the trees were in fruit, 22.06% of the baboons' food intake was *P. biglobosa*, with a total of 5% over the 3.5 year observational period. Olive baboons consumed both ripe and unripe seeds; however, the feeding process differed based on the ripeness of the seed. For ripe seeds, the pods were carefully peeled and then both the seeds and accompanying pulp were consumed. In contrast, the unripe pods were eaten directly and occasionally the pulp was spit out. (Kunz and Linsenmair, 2007). Kunz and Linsenmair (2007) investigated the potential medicinal benefits of olive baboon seed-swallowing behavior. This specific feeding method for unripe pods yields seeds that are hard and coarse, which are two of the main qualities attributed to the effectiveness of parasite removal found by Garber and Kitron (1997).

Although the occurrence of the seed-swallowing phenomenon has been established, it is also important to examine possible explanations for this behavior. Garber and Kitron (1997) examine why the two varieties of tamarins they studied would fill their small digestive tracts with large seeds when such a large quantity of seeds offers no nutritional value. In addition to increasing feeding efficiency and decreasing predation risk, another possibility is that the size and volume of the seeds passing through the intestines may result in the expulsion of parasites. Among the four common types of parasites found in primates of the region, acanthocephalans *(Prosthenorchis elegans)* are the most abundant and consequently, a major cause of disease and death in the tamarin population. Garber and Kitron (1997) found that 19% of wild *S. geoffroyi* were infected with at least one of these parasites. It was then determined that 13-40% of the volume of the small intestine of *S. geoffroyi* was filled by voided seeds. Due to the large dimensions of the seeds and the small area in which they are stored, it is likely that chafing and irritation of the intestinal lining is occurring. A related study confirmed, through chemical analysis of *Annona squamous*, that unripe seeds have little nutritional value and have no specific chemical effect on any common parasitic species (Negre, et al., 2006). Therefore, the physical properties of the seeds must have a specific function in parasite control in order for them to be effective. This habit of swallowing very large seeds in comparison to intestinal size suggests the seeds' role in parasite removal. *P. elegans* periodically detach themselves from the intestinal lining in order to find new location (Garber and Kitron, 2007). While loose, it seems very plausible that the large, hard seeds could extricate or harm the parasite. Thus, continuously having seeds pass through the intestine would disrupt and inhibit the ability of the acanthocephalans to attach to the lining wall in the first place. Also, this study found that any damage to parasites from the seeds was likely to be fatal. Such findings indicate that seed-swallowing is a highly effective method of self-medication against parasites that these tamarins and likely many other species of primates utilize (Garber and Kitron, 2007).

The verified seed-swallowing behavior of primates is not only beneficial for the animal, but research suggests that this is also advantageous to the trees. This relationship, which involves advantages to both organisms, is a mutualism (Marcus, 2009). Primates benefit by using the seeds of the flowering plant as a mechanism for seed dispersal. Likewise, plants benefit by having a reliable, effective mechanism of seed dispersal in the excrement of primates. Effective seed dispersal by vertebrates who engage in seed voiding is characterized by four main factors. These consist of how the fruit is handled when it is picked, the acidity of the chemicals in the stomach to which the seeds are exposed, whether the seeds are eaten individually or as a group, and the distance the seeds travel from the parent tree (Garber and Kitron, 1997). Holbrook and Loiselle (2009) examined the effectiveness of primates as seed dispersal agents by comparing primates and toucans in two similar sites in eastern Ecuador. Primates and toucans were found to be dispersers of *Virola flexuosa* seeds, which relys entirely on vertebrates for seed dispersal. These two groups alone accounted for up to 85% of the total seeds dispersed for this species at both sites. Primates, specifically, consumed more seeds per visit than any other disperser (Holbrook and Loiselle, 2009). Similarly, in a population of Papio anubis in north Ivory Coast, primates were responsible for 10.4% of the seed dispersal of *Parkia biglobosa* (Kunz and Linsenmair, 2007). Another study found that seeds swallowed by *Saguinus mystax* and *Saguinus geoffroyi*, two species of tamarins found in South America, were highly viable after excretion. When tested, the recovered seeds germinated 51-83% of the time. Additionally, the tamarins were also highly effective dispersers when looking at the dispersal distance of the swallowed seeds. The mobility of the tamarins allowed for 87% of the *Inga alba* seeds to travel more than 100 meters from their original source (Garber and Kitron, 1997).

The ecological relationship between primates and flowering trees, though beneficial to both, poses a severe threat to both organisms, should something happen to either of the species involved. Quantitatively restricted seed dispersal is a term that applies to the factors that contribute to dispersal limitation. These include the number of seeds dispersed from parent trees that are limited by the disperser's (in this case, primates) activity and behavior. It also predicts that the seeds dropped from the tree, and not consumed by the disperser, will not be dispersed (Holbrook and Loiselle, 2009). This aspect of the mutualism and the potential effects of dispersal limitation were studied by Holbrook and Loiselle (2009). Predatorial visits by primates to *Virola flexuosa* were significantly greater at the non-hunted sight than at the sight that was frequently hunted by indigenous people of the area. There was also a 25% difference in the number of seeds removed from fruiting trees in the hunted versus non-hunted site. Data suggest that dispersal is being limited to a larger extent at the site where large frugivores are being hunted. Not only were the dispersers less effective at dispersing the seeds at the hunted site, but species hunted by local farmers frequented the non-hunted site 30% more than the hunted sight (Holbrook and Loiselle, 2009). Because the majority of seed dispersal is carried out by relatively few species, conservation of these dispersal agents is essential not only for the preservation of the animal species but also the plant species they disperse. This study reveals some of the major long-term implications of hunting. If unregulated poaching persists in these areas, there likely will be changes in seed dispersal patterns, seed predation rates, and drastic changes in plant species composition and diversity at the site. In an extreme case, this hunting could lead to widespread loss of frugivore species, which would mean the extinction of many tropical flowering tree species that rely exclusively on these dispersers (Holbrook and Loiselle, 2009).

Seed and leaf-swallowing are important processes that are critical to the health of many primates. These are simple solutions to a potentially major problem that could threaten many primate populations that have no other means of ridding their digestive tracts of these debilitating parasites. The necessity of these processes coupled with the potential for trees to gain reproductive advantages through effective seed dispersal make for a classic mutualism. Both the primates and trees rely equally on each other for survival. This ecological relationship is arguably equally as important as the sum of its parts.

The research that has been, and will be conducted, on primates, seed dispersal, and especially self-medication, all have potentially larger implications for humans as well. Future studies that could yield great medicinal discoveries involve looking at the plants used by primates and other organisms for self-medication and identifying a chemical composition suitable for curing or aiding in treatment of human diseases and illnesses. This research holds with it the promise of endless possibilities for not only discovering more about primates, but also more about ourselves.

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