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Evolutionary biology:
Dirty eating for healthy living

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As babies, we are warned by our mothers not to eat dirt, but as adults some of us do it anyway and dignify it with the name of geophagy. The regular and intentional consumption of soil, by itself or mixed with food, has been recorded from traditional human societies on all continents, especially among pregnant women1-4. Geophagy has also been documented in many species of mammals, birds, reptiles, butterflies and isopods, especially among herbivores5-9. Why do they and we do it? Proposed biological functions of geophagy have now been tested by James Gilardi and co-workers10, who uncover a fascinating evolutionary arms race between plants and their would-be animal consumers.

The dirt-eaters studied were Peruvian Amazon rainforest parrots, of which a thousand or more individuals of 21 species gather early each morning at certain sites with exposed bare soil on river banks or cliff faces. Because these sites are ideal for viewing and photography, they attract 4,000 bird-watching tourists each year, support 500 jobs in the local ecotourism industry, and earn Peru about US$1,000 per year per individual wild macaw. The birds' taste in dirt is highly specific: for instance, they congregate not just at one particular bend of the Manu River but at one soil band running hundreds of metres horizontally along that bend, spurning the dirt in bands one metre above or below the preferred band. Gilardi et al. tested possible functions of geophagy by comparing the physical and chemical properties of soil samples from the preferred and rejected bands.

The commonest explanation for geophagy in birds is to provide grit8. Because birds lack teeth, many ingest pebbles or coarse soil with which to grind food in their gizzards. Preferred particle sizes of grit increase with bird size, from 0.5 mm for sparrows to 2.5 cm for ostriches. However, Gilardi et al. found that the soil preferred by Peruvian parrots is very fine: only 5% of it by volume is coarse sand exceeding even 0.05 mm in particle diameter. Most of it is clay less than 0.2 m in particle diameter, and preferred soils contain only a quarter as much coarse sand and nearly twice as much fine clay as rejected soils. So parrots are not eating soil to get grit. On reflection, this is not surprising: parrots have no need for grit because their strong, sharp bills can shred the hardest nuts.

A second function of geophagy, suggested for livestock, wild ungulates, rabbits, butterflies and pregnant women, is to provide essential minerals6,7. Soils sold in Ghanaian markets to pregnant African women are richer in iron and copper than the dietary supplement pills made by pharmaceutical companies specifically for prenatal use. But Gilardi et al.10 found that soils preferred by parrots contain lower available quantities of most biologically significant minerals than non-preferred soils, and much lower quantities than the parrots' preferred plant foods. Hence, unless the parrots are making a big mistake in their taste preferences, they are not selecting soils for mineral content.

A third function of geophagy, proposed for ungulate livestock, is to buffer the rumen contents6. Because parrots lack a rumen, it will come as no surprise that their preferred soils have no more buffering capacity than distilled water.

What, then, do the parrots actually gain from ingested soil? It turns out that they regularly eat seeds and unripe fruits whose content of alkaloids and other toxins renders them bitter and even lethal to humans and other animals. Because many of these chemicals are positively charged in the acidic conditions found in the stomach, they bind to clay minerals bearing negatively charged cation-exchange sites[2,3,5,9]. That's why experienced tourists visiting destinations with poor sanitation carry medicines such as kaopectate (high in clay minerals) to adsorb the toxins. That's also why peasant farmers and hunter-gatherers throughout the world often mix bitter but otherwise nutritious plant foods (like acorns and wild potatoes) with selected soils before consumption[1-3].

Peruvian parrots behave like sophisticated human tourists and hunter-gatherers. Their preferred soils were found to have a much higher cation-exchange capacity than adjacent bands of rejected soils -- because they are rich in the minerals smectite, kaolin and mica. In their capacity to bind quinine and tannic acid, the preferred soils surpass the pure mineral kaolinate and surpass or approach pure bentonite. Clearly, parrots would be well qualified for jobs as mining prospectors.

Gilardi et al. confirmed this hypothesis with two sets of bioassays. First, they exposed brine shrimp (the toxicologist's test animal of choice) to extracts of seeds routinely consumed by macaws. Many of the brine shrimp died, confirming the toxicity of the parrots' diet. But mixing the solutions or extracts with soil preferred by parrots reduced the effective toxin loads by 60-70% and improved shrimp survival. Second, Amazon parrots were given an oral dose of the alkaloid quinidine with or without preferred soil, and quinidine levels were measured in the parrots' blood for three hours as absorption took place from the gut. Providing soil along with the quinidine reduced absorbed quinidine blood levels by 60%.

What is the evolutionary significance of plant toxins and animal anti-toxin behaviour? From a plant's evolutionary perspective, a seed should be high in nutrients to support germination and seedling growth; the ripe fruit around the seed should also be nutrient-rich and attractive to animals, encouraging them to pluck and eat the fruit and disperse the seed. On the other hand, the seed itself should be repulsive to animal consumers, inducing them to regurgitate or defaecate it, and the unripe fruit should be repulsive, lest animals harvest it before the seed is viable. From an animal's evolutionary perspective, an ability to defeat the plant's toxin defences would enable it to obtain the nutrients in the seed as well as those in the ripe fruit, and to outcompete other animal consumers by harvesting the fruit while it is unripe and still unpalatable to them.

Any textbook of animal biology describes the resulting evolutionary arms race, in which plants evolve increasingly potent toxins (such as strychnine and quinine), and animals evolve increasingly potent means of detoxification. While enzymatic detoxification has previously received the most attention, the work of Gilardi et al.[10] and the wide distribution of geophagy among animal herbivores suggest an additional important means of detoxification by adsorption on ingested soil minerals.

A host of interesting questions now comes into focus. How do parrots discover the best soils -- can they discriminate among soils immediately by texture and taste, or must they experiment with various soils mixed with toxic food and discover which soil assuages their upset stomach? Might the availability of suitable geophagy sites limit herbivore distributions and merit concern from conservation biologists? Only certain species of local herbivores are reported as visiting geophagy sites: why? To return to our youthful dirty habits, do curious dirt-licking babies deserve our encouragement for their experiments with self-medication?

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