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Zoopharmacognosy: What is Animal Self-Medication?

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Abstract

The emerging field of zoopharmacognosy reveals the phenomenon of animals actively seeking and utilising medicinal substances from their surroundings to address a variety of health hazards. This behaviour challenges the traditional perception of animals as passive recipients of medical care, emphasising their inherent ability for self-care.

Michael Alan Huffman was one of the pioneers of zoopharmacognosy, thanks to his important studies on Gombe chimpanzees, which reveal behaviours such as leaf swallowing and bitter chewing as forms of self-medication. Additionally, Cindy Engel's book "Wild Health" has helped introduce animal self-medication to the public, cataloguing over 320 animal species and 137 plant species.

What has been discovered and is continuously being researched is that animals employ a diverse array of materials for self-medication purposes, including plants, soil, and insects. Administered in various ways—ingested, rubbed into fur, or used in nests or burrows—these substances serve various functions such as balancing mineral levels in their bodies, countering plant secondary compound poisoning, combating pathogens and parasites, and treating injuries. For instance, birds utilise ants to rid themselves of ectoparasites, while certain primates ingest clay-rich soil to detoxify harmful compounds consumed with their food.

Understanding the mechanisms and effectiveness of animal self-medication holds immense promise for both animal welfare and human health. By identifying the medicinal properties of natural substances and how animals utilise them, researchers can reveal new pathways for drug discovery and therapeutic interventions. Furthermore, this knowledge can enhance the health and well-being of both captive and wild animals.

1. Introduction

In medical research, it is rare to observe healthy animals without invasive methods. Instead, new treatments are typically discovered through deductions and experiments in laboratories, rather than learning from observing other animals. Both in veterinary and human medicine, significant funds are directed towards fighting disease using gene therapy, costly medications, surgeries, and organ transplants, with minimal investment in studying how healthy individuals naturally resist disease. A cynical perspective might suggest that there's little profit in promoting health, but substantial profit in treating recurring illnesses.

Anyway, the widespread use of synthetic drugs in animal healthcare, mainly in livestock husbandry, has raised concerns about antibiotic and anthelmintic resistance (*Huffman, 2003*), suggesting a growing interest in exploring alternative approaches such as herbal medicine, probiotics, and behavioural interventions. These alternative methods not only offer potential solutions to mitigate antimicrobial resistance but also contribute to more sustainable practices in animal health management.

1.1 What is Zoopharmacognosy

In 1993, the term "zoopharmacognosy" emerged, originating from the Greek roots *zoo* (meaning "animal"), *pharma* (referring to "drug"), and *gnosy* (signifying "knowing"). It is referred to a multidisciplinary field dedicated to studying the self-medication behaviour observed across various animal species, in which they seemingly self-medicate by selecting and ingesting or topically applying plants, soils, insects, and even psychoactive substances to treat and prevent diseases. These self-medication strategies can be considered as adaptive survival skills refined by natural selection, often driven by a desire to immediately alleviate discomfort (*Jain et al., 2008*).

These behaviours can be grouped into four distinct modes:

1. Optimal avoidance or reduction of potential sources of disease transmission: Many wild animals instinctively steer clear of faeces, contaminated food, water, or substances that may carry pathogens.
2. Passive prevention (prophylactic): occurs when animals consume certain foods not because they are currently infested with parasites, but rather to reduce the risk of parasitism in the future.
3. Therapeutic treatment: it involves the deliberate ingestion of medicinal substances by sick individuals in response to specific afflictions.

4. Fumigation: the animal applies pharmacologically active substances externally to their bodies or living spaces. This practice aims to treat or control mainly ectoparasites.

However, determining which behaviours to prioritise as part of self-medication is not always easy. It involves considering various factors such as the context of the behaviour, the health status of the animal, and the potential medicinal properties of the substances involved.

In response to this complexity, Michael Huffman of Kyoto University has developed a comprehensive set of guidelines: firstly, the animal should exhibit signs of illness (lethargy, depression, anorexia, behavioural fever, basking behaviour), preferably supported by quantifiable tests confirming sickness. Secondly, it should actively seek and consume a substance not part of its regular diet, ideally without nutritional benefits. Finally, the animal's health should subsequently improve within a reasonable timeframe consistent with the known pharmacology of the substance (*Huffman, 1997*). If the observed behaviour adheres to these phases, then it can be classified as self-medication.

Nonetheless, while these criteria provide valuable guidance, they likely capture only a fraction of instances of animal self-medication. This is because they may overlook certain factors that contribute to the complexity of the behaviour. For instance, an animal may be unwell without displaying symptoms or the consumed substance may still be part of the animal's regular diet but ingested in larger quantities as a form of self-medication.

Moreover, the guidelines may not fully consider factors such as social dynamics, environmental conditions, and individual differences in animal physiology and metabolism, which could influence self-medication behaviours but might not be adequately addressed by the existing criteria.

As such, while Michael Huffman's guidelines provide a valuable framework for identifying instances of self-medication, researchers must remain mindful.

1.2 History of Zoopharmacognosy

Even in the past, scholars like Aristotle observed interesting behaviours suggesting that animals instinctively know about medicinal substances. For instance, in his work "Historia Animalium," Aristotle observed wolves ingesting specific types of earth in times of severe hunger.

Similarly, in "Libro de las Utilidades de los Animales," al-Durayhim (14th century) explores the behaviours of animals employing plants and other substances to ward off parasites and treat illnesses (*Mezcua et al., 2019*).

In fact, the observation of animal behaviour has long been interconnected with humanity's quest for survival and understanding of the natural world. For instance, when seabirds suddenly gather near the land, it often means a storm is on the way. Similarly, when small animals start acting restless, it serves as a warning to be prepared for an earthquake.

Indigenous peoples around the world have long relied on their observations of animals to learn about the properties of plants. This intimate knowledge of the natural world has been passed down through generations, forming the basis of traditional medicine and cultural practices.

Some indigenous tribes of the Amazon attribute their utilisation of *Banisteriopsis caapi*, commonly referred to as 'ayahuasca,' to their observations of jaguars. Within the Amazon rainforest, jaguars have been documented chewing on the plant's bitter roots, bark, and leaves, exhibiting subsequent signs of disorientation, including rolling on their backs (*Huffman, 2021*). A comparable behaviour was observed across various felid species, such as domestic cats when in contact with catnip.

Shamans from the Tukano and other Amazonian cultures incorporate the plant into ritual ceremonies, while hunters use it to sharpen their alertness and vision. It is believed to confer upon them 'jaguar eyes,' enhancing their ability to see clearly in the forest's darkness for more effective hunting. This belief is supported by the plant's capacity to dilate the pupils, potentially improving night vision. Among the Tukano, the hallucinogenic properties serve to facilitate communion with the spirit realm and to evoke a shaman's healing prowess.

The consumption of ayahuasca by jaguars could tentatively be viewed as prophylactic self-medication or therapeutic if there was evidence showing that jaguars deliberately use the plant for its anthelmintic properties. Nonetheless, a more comprehensive understanding of the animals consuming hallucinogenic plants necessitates further investigation.

Similarly, the discovery of caffeine-containing plants can be traced back to indigenous cultures. According to folklore, in what is now Ethiopia, a young goatherd named Kaldi noticed that both young and old goats becoming friskily moving after consuming red berries from a wild coffee bush. Upon hearing this tale, a local monastery's abbot acquired some of the beans, roasted them, and brewed them into a hot beverage. He named it 'Kahveh', meaning stimulating or invigorating, which eventually led to the terms 'café' and 'coffee' (*Plotkin, 2000*). The monks discovered that this brew helped them stay awake during nightlong religious ceremonies, while its role as stimulants for wild animals to combat fatigue may have evolutionary advantages.

In Table 1, additional examples of folklore derived from observed instances of animal self-medication are presented.

Plant species	Animal species (Mode of self-medication)	Ethnomedicinal uses	Observed animal behavior leading to its use by humans
Aeschynomene cristata Vatke var. *cristata* (Fabaceae)	Crested porcupine (*Hystrix africaeaustralis; H. cristata*) (therapeutic treatment: 4)	Antibiotic properties suggested. Root concoction used to treat patients with sexually transmitted disease and other illnesses with symptoms resembling dysentery in East Africa. Used as a treatment for secondary infections in AIDS patients.	Porcupine dug up and ingested the toxic root. It subsequently recovered from dysentery-like symptoms (bloody stools).
Amanita muscaria (L.) Lam. (Amanitaceae)	Reindeer, Caribou (*Rangifer tarandus*) Brown bear (*Ursus arctos; Ursus* spp.) (stimulant, tonic food: 3)	Hallucinogenic effect used to communicate with the spirit world and to meet powerful spirits with 'courage'; induces a temporary sense of euphoria. Used to increase strength for hunting, walking long distances, and enduring cold temperatures.	After eating the mushrooms, reindeer move around as if intoxicated. In the mating season, bears that ingest them are said to act with 'courage', losing the inhibition to confront others.
Banisteriopsis caapi (Spruce ex Griseb.) C. V. Morton (Malpighiaceae)	Jaguar (*Panthera onca*) (stimulant/therapeutic treatment: 3 or 4)	Used in ceremonies for its hallucinogenic properties, to heighten alertness and night vision ('jaguar' eyes) while hunting. Used as an antiparasitic treatment.	After chewing on the bark and roots, leopards roll on the ground in an intoxicated state like cats with catnip.
Erythroxylum coca Lam. (Erythroxylaceae)	Llama (*Lama glama*), three-toed sloth (*Bradypus tridactylus*), Hoffmann's two-toed sloth (*Choloepus hoffmanni*) (stimulant/therapeutic treatment: 3 or 4)	Used in the Andes as a stimulant, treatment for altitude sickness, abatement of hunger, reduction of fatigue, fast-acting antidepressant, increases sexual appetite. It is used as a comprehensive remedy for restoring balance to the digestive system. The masticated leaves are held in the mouth for relief of painful oral lesions and toothaches.	Llama moved to lower elevations in the Andes were observed to chew on coca leaves as an alternative food source in the new habitat. Herders observed that these leaves appeared to give the llama extended stamina. Similar legends attribute human use of coca for this purpose by watching sloths and monkeys eat coca and behave in a similar way to the llama.
Ligusticum porteri Coult. & Rose (Apiaceae)	Black bear (*Ursus americanus*), Brown bear (*Ursus arctos*), Kodiak bear (*Ursus arctos middendorffi*) (therapeutic treatment: 4)	Roots chewed to increase endurance. Possess antiviral, antibacterial, antifungal and anti-inflammatory activities. Roots support healing of respiratory conditions, indigestion, headaches, dizziness, sinusitis, and arthritis. Taken to ease breathing at higher altitudes, and for long-distance hiking.	Bears consume the roots after emerging from winter hibernation in a weakened state, to restore strength, or when wounded or sick. Roots are chewed, and then, mixed with saliva, rubbed into their fur to treat skin infection and possibly wounds.
Ophiocordyceps sinensis [Berk.] Sung GH et al. (*Cordyceps sinensis*) (Ophiocordycipitaceae)	Yak (*Bos grunniens*) (stimulant, tonic food: 3)	Ayurveda and TCM medicine used for enhancing vigor and vitality, erectile dysfunction, as a female aphrodisiac, to treat bronchitis, cough and cold, rheumatism, arthritis, chronic pain, sciatica, low blood pressure, dizziness, and diabetes.	Fungus is eaten by yaks at the beginning of the breeding season.

Tab. 1 Case studies of ethnomedicinal plants in folklore and ethnographical studies purportedly derived from observed instances of animal selfmedication.

The observation of animal behaviour has undergone a significant shift with the rise of advanced technology, marking a pivotal moment in the field of animal studies. While this technological leap brings numerous benefits, such as enhanced data collection and analysis capabilities, it also presents certain disadvantages, like the potential loss of vital information that can only be detected through visual observation.

One notable example is the observations made by Jane Goodall, who spent forty years studying the behaviour of wild chimpanzees in Africa. It was through one of these observations that the world became aware of the possibility that chimpanzees create and use tools (*Engel, 2002*).

2. Natural sources of medicines used by animals

Across diverse species in the animal kingdom, a wide spectrum of behaviours in which animals employ natural substances such as plants, dirt, and insects to address their illnesses, is observed. Table 2 presents several examples of materials utilised by animals and their medicinal properties.

Source of medicine	Name of the material used by animals	Description of medicine
Dirt	Clay-rich termite mound soil	Clay is an effective binding agent as its chemical structure allows other chemicals to bond with it and thus lose their reactivity. Clay is an effective deactivator of toxins from diet or pathogens and is the primary ingredient of the kaolin found in many over-the counter treatments for gastrointestinal malaise in humans.
	Clay-rich volcanic rock	Contain fewer minerals than the surrounding top soil but the clay content is high and found to be more effective at binding alkaloids and tannins than pure pharmaceutical kaolinite.
	Japan soil	Soil has predominantly higher levels of the clay minerals and can absorb dietary toxins, present in the plant diet or those produced by microorganisms.
Insects	Ants that spray formic acid	They control parasitic mites.
Plants	*Clematis dioica* Linn., *Piper marginatum* Jacq., *Sloanea terniflora* Standl.	These three plants are used to treat skin irritations or repel insects.
	Ligusticum porteri J. M. Coult. & Rose	Contains coumarins-fragrant organic compounds which may repel insects when topically applied.
	Daucus carota Linn.	The plants are highly aromatic and contain monoterpenes and sesquiterpenes that are harmful to bacteria, mites and lice. Particularly effective against the bacteria, *Staphylococcus aureus*, *S. epidermidis* and *Psuedomonas aeruginosa*.
	Azadirachta indica A. Juss.	Powerful insecticide.
	Caesalpinia pulcherrima (Linn.) Sw.	Useful in outbreak of malaria.
	Vernonia amygdalina Delile	Used to treat malarial fever, schistosomiasis, amoebic dysentery and other intestinal parasites and stomach disorders.
	Aspilia sp.	Used in treating stomach upset and cough.
	Aspilia mossambicensis (Oliv.) Wild	This plant contains, thiarubrin-A which is known to be antibacterial, antifungal and anthelmintic.
	Apuleia leiocarpa J. F. Macbr. and *Platypodium elegans* Vog.	Ingesting its leaves may increase estrogen levels in the body, thereby decreasing fertility.
	Enterolobium contortisiliqua (Vell.) Morong	Increase the monkey's chances of becoming pregnant because the plant contains a precursor to progesterone (pregnancy hormone) called stigmasterol.

Tab. 2 Various sources materials used by animals for self-medication

2.1 Plants and their secondary compounds

Plants produce a diverse array of secondary metabolites, which were traditionally believed to lack a defined role in further metabolism (*Harborne, 2001*). These secondary metabolites are synthesised and stored in various plant parts, predominantly in peripheral regions. Initially considered waste products of primary metabolism, stored due to the absence of an efficient excretory system, it has since been realised that these compounds play a vital role in the plant's defence mechanisms (*Raman & Kandula, 2008*).

To deter predators, the emitted odour of a plant should ideally be enough, if not, the initial taste must be sufficiently unpleasant to deter further damage. Many toxic secondary compounds exhibit a bitter or aromatic taste and are seldom consumed by most animals. Examples include sesquiterpenes, saponins, and alkaloids, which primarily function to prevent predation by animals (*Huffman, 2003*). Some notable examples are atropine from the belladonna plant, psilocybin from "magic mushrooms," and mescaline from the peyote plant.

Moreover, certain plants produce secondary compounds that can trigger skin irritation upon contact. For instance, poison ivy secretes urushiol, a resin that commonly induces dermatitis in humans.

Certain secondary compounds mimic hormones, disrupting herbivore growth and reproduction. For example, caffeine and nicotine impair insect development.

Additionally, some plants release secondary compounds into the soil, inhibiting the growth of neighbouring plants. The roots and leaves of the walnut tree (*Juglans nigra*) release juglone, which adversely affects most nearby plants.

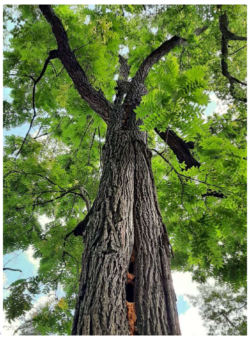

Fig. 1 Juglas nigra

Many secondary compounds are volatile, serving as warning signals or cries for help. For example, as a spider mite feeds on a cucumber plant, the plant releases terpenoids that attract predators of the spider mites (*Takabayashi et al., 1994*).

Among the volatile secondary compounds there are also flavonoids, which serve to attract pollinators, deter pests, and shield plants from ultraviolet radiation.

Animals exhibit an intriguing ability to use plant metabolites for various purposes, ranging from stimulants to antidotes. Despite these compounds being designed to deter consumption, they can paradoxically possess medicinal properties under certain conditions, this concept is named hormesis. Hormesis, derived from the Greek word meaning "to excite," describes the beneficial response of an organism to low doses of stressors or harmful substances. In the context of plant secondary metabolites, hormesis suggests that small doses of toxins may stimulate adaptive responses within animals, leading to enhanced physiological functions or resilience against environmental stressors.

Therefore, the plant toxicity is heavily dependent on dosage, which itself is influenced by several factors. Firstly, the sex of the plant can significantly impact the potency and composition of its secondary metabolites (*Elmqvist et al., 1991*). For instance, certain compounds may be more concentrated in male or female plants, affecting their efficacy as medicinal agents. Secondly, different parts of the same plant, such as leaves or roots, may contain varying concentrations of bioactive compounds. Finally, changes in environmental factors such as temperature, sunlight, and precipitation can influence the synthesis and accumulation of secondary compounds in plants, thereby affecting their medicinal properties (*Bryant et al., 1991*).

2.2 Soil

Geophagy, the deliberate consumption of soil, dirt, or rock, is a behaviour observed across various species with different ecological niches. While it is most commonly associated with herbivores, the fact that carnivores also engage in geophagy suggests its broader significance in animal health, so much that William Mahaney, director of the Geophagy Research Unit at York University, contends that all instances of geophagy can be viewed as a form of self-medication.

Ingested soil analyses often reveal the presence of mineralogically similar clays, including halloysite, metahalloysite, and kaolinite (*Lozano, 1998*). These clays possess properties that make them effective binding agents or even natural remedies against pathogens present in the gut.

Fig. 2 A flock of Green-winged macaws eating clay along the Heath River in Southern Peru. Photo: Daniel Blanco.

The multifaceted nature of geophagy reveals its adaptive potential. One crucial function of soil consumption is its role in regulating gut pH (*Oates, 1978*) and aiding in digestive processes. By ingesting certain types of soil, animals can stabilise the acidity levels in their digestive systems, mitigating issues such as indigestion or diarrhoea.

Moreover, soil provides a rich source of essential minerals, such as iron, calcium, and zinc, which may be lacking in their primary diet (*Davies et al., 1988*) and it also serves as a means of addressing specific nutritional hungers, such as the sodium one (*Mahaney et al., 1990*).

Finally, geophagy acts as a detoxification mechanism, enabling animals to neutralise the harmful secondary compounds (*Johns &* Duquette*, 1991*).

2.3 Insects

Numerous insects have evolved fascinating strategies to defend against predators, infections and parasites. Some synthesise defensive toxins internally, while others sequester them from their diet, storing them within their bodies.

In the avian world, a behaviour known as "anting" has been observed in over two hundred bird species (*Potter, 1970*) and involves birds utilising ants as a natural anti-parasitic method.

This behaviour manifests in two primary forms: active anting, where birds actively crush ants and rub them vigorously through their plumage, and passive anting, where birds may rest in areas with high concentrations of ants, typically near ant nests (*Mamillapalli et al., 2016*).

The practice of anting serves various purposes beyond parasite control. It is believed to aid in the maintenance of plumage and skin health, to provide relief from irritation, as well as to prevent or reduce the abundance of skin parasites (*Potter, 1970; Clunie, 1976; Ehrlich et al., 1986*).

The secretion of toxic fluids by ants, particularly formic acid, is essential for the efficacy of anting. Formic acid not only eliminates chewing lice upon contact but also emits vapours capable of eradicating lice and feather mites, along with the immediate analgesic effects that alleviate discomfort. Moreover, ants produce a diverse array of secondary compounds beyond formic acid, including auxins and beta-hydroxyl fatty acids, which possess antibacterial and antifungal properties (*Clayton et al., 1993*).

In addition to birds, certain mammals exhibit fur rubbing behaviour with insects. Species such as capuchin and owl monkeys, as well as lemurs, are known to engage in this behaviour. They occasionally rub their fur with insects, in particular ants and millipedes. Millipedes are of particular interest as they contain benzoquinones, chemical compounds recognized for their insect-repellent properties (*Valderrama et al., 2000*).

Fig. 3 Millipede

3. Health Hazard

In the natural world, animals encounter a multitude of health hazards that can severely impact their survival and overall well-being. These hazards include managing mineral imbalances, the ever-present risk of poisoning, and threats from pathogens and parasites. Despite the Western perception of animals and ecosystems co-existing in a harmonious equilibrium, the reality is quite different. Animals are in a constant struggle for survival, continuously dealing with challenges.

3.1 Managing Minerals

Ensuring an optimal mineral balance is crucial for the well-being and metabolic balance of animals. When a sick animal lacking specific minerals actively search and consumes those minerals to address its health issues, it exhibits a form of self-medication.

The mechanism behind this behaviour is subject of continuous research. One possibility is hedonic feedback, where animals instinctively choose foods that are immediately pleasing to their senses. This innate mechanism links taste sensations like sweetness to energy-rich foods, bitterness to potential toxicity, and saltiness to the presence of essential sodium. Alternatively, animals may rely on postingestive feedback, learning from the consequences of their dietary choices and adjusting their feeding behaviour accordingly.

Consider, for example, osteophagy, also known as bone consumption, which has been documented in herbivores such as giraffes (*Western, 1971*) and farm cattle (*Blairwest et al., 1992*). A likely explanation for this behaviour is that the animal is instinctively trying to balance its phosphorus levels, given that phosphorus is a major component of bones, and that it has been shown that animals exhibiting this behaviour were deficient in this mineral.

Another highly sought-after mineral is salt, crucial for various physiological functions such as osmotic balance, nerve impulse transmission, and muscle function. Herbivores are particularly at risk of sodium deficiency due to their plant-based diets, as a consequence they employ clever strategies to supplement their sodium intake, like licking plants, rocks, or sweat, as observed in African buffalo (*Engel, 2002*) and even urine, as seen in reindeer (*Siegel, 1989*).

In regions where they are accessible, herbivores often graze near water sources, which are abundant in aquatic plants. These plants typically possess elevated sodium levels compared to terrestrial vegetation but offer lower energy intake. For instance, moose in Isle Royale predominantly consume aquatic plants during summer when

Fig.4 Moose in Isle Royale National Park

they are abundant, switching to land plants during other seasons to meet their energy requirements. This strategic foraging allows moose to optimise their energy intake while ensuring an adequate sodium supply year-round (*Belovsky, 1981*).

3.2 Poisoning

Natural selection has advantaged the skills needed for animals to avoid and cope with poisoning, a capacity unfortunately lost by many domesticated animals.

It's important to note that animals have evolved mechanisms to detect only those toxins that are typically present in their environment. This adaptation ensures their survival by allowing them to avoid ingesting harmful substances. Consequently, conservation managers must be careful when releasing or translocating animals into unfamiliar habitats to prevent inadvertent exposure to new toxins.

Among animals, herbivores possess a rich evolutionary history of dealing with plant defensive chemicals and are generally better adapted to handle plant poisons compared to omnivores, who in turn are more skilled than carnivores.

Herbivores have at least two broad strategies for avoiding plant toxins. One approach is specialisation, where they focus their resources on dealing with a limited range of toxins. The other strategy is generalisation, where they mitigate the toxin load by consuming smaller amounts of a wider variety of toxins. The maned sloth has a specialised diet primarily consisting of leaves, drawn from approximately ten specific plant species. Moreover, it exhibits a discerning preference for consuming young leaves, which typically contain lower levels of tannins, thereby reducing the toxin load it must contend with. This dietary selectivity is a strategic adaptation to its slow metabolism and constrained detoxification capabilities (*Chiarello, 1998*). On the other hand, the mountain gorilla displays a more generalised dietary behaviour, consuming almost everything it can reach.

While, individual animals possess the remarkable ability to learn about poisonous substances through various means. One such method involves observing the dietary choices of other individuals, preferably those within their own species (*Galef et al., 2000*). This social learning mechanism allows animals to glean valuable information about what is safe to consume and what should be avoided. Otherwise, through personal experience, animals can develop aversions to specific foods after ingesting them and experiencing negative consequences, such as illness. This learned avoidance of certain foods, known as conditioned aversion, serves as a vital survival strategy by helping animals steer clear of potentially harmful substances in the future.

Furthermore, mammals have unique opportunities to acquire knowledge about safe foods even before birth. While in the uterus, they can familiarise themselves with the taste and smell of safe foods through their mother's diet, which is transmitted to them via amniotic fluid. Additionally, during lactation, they continue to learn from their mother's milk and by sampling the foods she consumes (*Mirza et al., 1994*).

As a result of these learning processes, many animals exhibit a tendency to prefer familiar foods while exercising caution when encountering new food items. This phenomenon, known as neophobia (fear of the unfamiliar), reflects a natural aversion to unknown substances and serves as an adaptive response to minimise the risk of ingesting potentially harmful or toxic foods. Rats are the most famous neophobes: they cautiously sample small quantities of any novel food, then they wait, and if they do not experience any adverse effects, they will return to consume the remainder of the food.

However, there are instances where animals succumb to poisoning, often due to factors such as extreme hunger, confinement, distraction by predators (*Metcalfe et al., 1987*), or social hierarchy. These circumstances can impair an animal's ability to discern between low-quality food and access essential resources. For example, individuals lower in social status may face greater challenges in securing high-quality food sources, leading them to consume potentially toxic food items.

Additionally, wild animals may fall into poisoning when typically safe plants unpredictably become toxic. For instance, during periods of drought, plants may increase their production of secondary compounds, which can catch animals off guard, as they may be used to consuming these plants without adverse effects under normal conditions.

Due to the dynamic nature of food toxicity, some animals have developed smart ways to use natural processes that break down toxins.

For instance, pikas living in the highlands of North America prefer to eat *Acomastylis rossii*, an alpine oat species rich in phenolic compounds such as tannins. To cope with the high phenolic content of this plant, pikas have developed a specific way of behaving: during the summer months, they gather and store *Acomastylis rossii*; subsequently, they allow time for enzymatic processes to gradually degrade the phenolic compounds, thereby diminishing the plant's astringency over time; finally, by the arrival of winter, when food resources become scarce, pikas can safely consume the now-milder

Fig. 5 Pika (Ochotona spp.) sniffing the flower of Acomastylis rossii.

Acomastylis rossii without encountering the adverse effects associated with high phenol concentrations (*Dearing, 1997*).

In instances of accidental poisoning, animals commonly resort to ingesting emetics to induce the vomiting reflex, as exemplified by the consumption of grass by cats.

However, when poisoning occurs persistently, perhaps due to a diet containing various toxic substances, animals employ diverse coping mechanisms. As discussed in the preceding chapter, the pursuit of salt is a prominent aspect of many animals' lives. Sodium is indispensable for all metabolic processes, including detoxification. Herbivores, in particular, exhibit a pronounced need for sodium, not only because their plant-based diets may be deficient in minerals but also due to the loss of sodium during the detoxification and metabolism of plant secondary compounds.

The tropical great blue turaco (*Corythaeola cristata*), a bird species that subsists on a diet abundant in fruits and leaves containing compounds toxic to other animals. Recent scientific findings have revealed that this species also consumes two species of sodium-rich aquatic plants. It is likely that by incorporating these plants into its diet, the turaco can effectively detoxify the secondary compounds present in its primary food sources (*Chin et al., 1997*).

Fig. 6 Great blue turaco

Another interesting behaviour observed in animals is their consumption of clay. Clay is composed of mineral-oxide layers arranged in parallel, enabling it to effectively bind with other molecules. Different types of clays have variations in their structure and properties; some are adept at adsorbing molecules onto their surface, while others excel at absorbing molecules into their structure (*Engel, 2002*).

Within the body, toxins are neutralised as they bind to clay particles, which are then expelled through faeces. Clays have demonstrated effectiveness in binding various toxins, including fungal toxins, internal toxins, man-made chemicals, and bacteria. They also provide protection to the gut by acting as an antacid and absorbing excess fluids, which helps alleviate diarrhoea..

In the rainforests of the Central African Republic, forest elephants and other mammals have established large treeless licks, many of which contain significant amounts of minerals such as sodium, magnesium, potassium, calcium, and manganese. What's particularly fascinating is that these licks consistently contain clay, comprising over 35% of their composition.

Fig. 7 Large area of forest are kept clear of vegetation by elephant's clay mining

The elephants' regular visits to these licks decrease only in September, coinciding with a shift in their diet from predominantly plant-based to a higher consumption of fruits (*Klaus et al., 1998*). This suggests that the presence of clay in these licks serves a specific purpose for these animals, perhaps to detoxify the secondary compounds of the ingested plants.

Finally, certain animals have been observed actively seeking and consuming charcoal. For instance, when deer, ponies, and bees are exposed to wood smoke, they tend to approach and consume the resulting charcoal. This behaviour suggests an innate attraction to charcoal, possibly due to its adsorptive properties and potential health benefits. Charcoal indeed, is primarily composed of carbon, which exhibits remarkable adsorption capabilities: it can absorb up to 4 times its weight. Its porous structure enables it to trap toxins, impurities, and odours. This property also extends to its potential medicinal applications, as charcoal has been used historically to treat various ailments, including poisoning and digestive issues.

Fig. 8 CC-BY Thomas Struhsaker, Medium Juvenile Eating Charcoal, July 1994, Jozani

Furthermore, there is evidence of animals, including wild elephants and domestic livestock, engaging in ash consumption (*Engel, 2002*). This behaviour may potentially serve as a form of self-medication, acting as an antacid due to the alkaline properties of ash, that alleviate digestive discomfort or to counteract acidic conditions within the gastrointestinal tract.

Charcoal and ash may also provide essential minerals like calcium and magnesium, contributing to overall health.

3.3 Wounds

The acknowledgment that animals experience pain has emerged relatively recently, challenging previous assumptions. Pain serves as a vital survival mechanism, functioning as a warning signal and an integral part of the health maintenance system in animals. When an animal experiences pain, it is alerted to potential harm or injury, encouraging immediate action to mitigate further damage and promote healing.

A study conducted by veterinary scientists at Bristol University sheds light on the pain and discomfort experienced by farm chickens. The researchers demonstrated that these birds as young as one month old could learn to self-medicate by selecting feed containing the painkilling analgesic carprofen. Healthy birds, on the other hand, tended to avoid the drugged feed, indicating that they found it unpleasant (*Danbury et al., 2000*). This behaviour demonstrates that broiler chickens experience pain and discomfort as a result of their rapid growth.

Moreover, pain acts as a motivator for animals to seek necessary care and treatment. Just as humans instinctively tend to their wounds, animals exhibit behaviours aimed at alleviating pain and promoting recovery. These behaviours can vary widely across species and environments but often include grooming, licking wounds, and seeking out natural remedies. Grooming behaviour involves cleaning and caring for wounds to prevent infection and aid in healing; while, licking wounds is an innate instinct observed in many animals, especially mammals.

This behaviour has numerous beneficial effects on wound healing. Firstly, animal saliva contains enzymes and antibacterial substances that aid in wound cleansing and infection prevention, it also helps maintain moisture in the wound, crucial for optimal healing, as moist environments promote cell migration and proliferation, resulting in faster tissue repair. Secondly, licking stimulates blood circulation in the affected area and promotes the production of growth factors, facilitating tissue healing. Finally, licking assists in the removal of dead tissue and debris, allowing healthy tissue to grow.

Fig. 9 Lioness (Panthera leo) licking her wounds.

Many species have been observed exhibiting behaviours that suggest they actively treat their wounds. For instance, wounded moose, elk, bears, and caribou have been observed rolling in clay, while pigs, deer, elephants and other animals wallow in mud (*Douglas-Hamilton et al., 1975*). Bears and deer may rub against resinous trees, while cattle and deer roll in sphagnum moss. Additionally, deer have been observed strolling out into salty seas, and various wounded animals are said to dip in cold water to staunch bleeding or numb discomfort (*Engel, 2002*).

A gorilla wounded in a battle was seen seeking strands of *Gallium*, a plant known for its wound-healing properties and using its forefinger to apply saliva and possibly plant extract to the injured area (*Fossey, 1983*). Likewise, a captive capuchin monkey built a tool by chewing one end of a stick to create a brush, which was then used to apply syrup (supplied as food) to the wound present in the pubic area (*Ritchie et al., 1988*). This syrup, with its strong sugar content, served as an effective ointment, offering both soothing and antibacterial benefits.

3.4 Parasites

In addition to competition and predation, parasitism represents a significant form of biotic stress encountered by all organisms (*Lozano, 1998*). The term "parasite" originates from the Latin form of the Greek word παράσιτος (*parasitos*), which translates to "one who eats at the table of another", in fact, by definition, it is a species that resides on or inside another organism, known as the host, and benefits by deriving nutrients at the other's expense (*Oxford Dictionary*).

Parasitism manifests in various forms, in base of the relationships between the parasite and the hosts:

1. Obligate Parasites: They rely entirely on the host to complete their life cycle. There are three subtypes:

   - Permanent Parasites: they remain in contact with the host for their entire lifespan. An example is mites, which reside on their host indefinitely.

   - Temporary Parasites: they engage with the host for a brief period during their life cycle. Mosquitoes, for example, feed on the host before departing.

   - Periodic Parasites: they interact with the host for an entire phase of their life cycle. Like ticks, which attach to their host for a specific period before detaching.

2. Facultative Parasites: they can survive independently of the host and only occasionally engage in parasitic activities.
3. Accidental Parasites: they inadvertently infest a host species different from their usual target. While they can survive for a limited time on the unintended host, they typically do not complete their life cycle there.

Parasitism includes both macroparasites such as helminths and arthropods, as well as microparasites like viruses, bacteria, protozoa, and fungi. It specifically excludes micro predators or organisms that merely seek shelter from their hosts.

Parasites can often coexist with their host without causing any measurable deleterious effect, but they are also opportunistic, and can quickly increase in numbers and overwhelm a host weakened by other forms of stress, such as malnutrition or reproduction (*Walzer et al., 1989*).

Parasites can undermine the host's immune system through two primary mechanisms. Firstly, hematophagous parasites directly diminish host fitness by continuously extracting blood and nutrients from the body. Secondly, parasites can serve as reservoirs for various deadly transmissible diseases, acting as carriers (vectors) that spread illnesses among host populations (*Mamillapalli et al., 2016*). Even parasite bites that do not transmit disease can leave the host vulnerable to fungal and bacterial infections through open wounds.

The coevolutionary relationship between hosts and parasites has led to the emergence of mechanisms through which hosts mitigate parasitic infections while parasites enhance their ability to infect hosts (*Hart, 1990*). Initially, hosts rely on their immune systems to combat invading parasites, however, some parasites have evolved strategies to circumvent these defences. For example, parasites may employ antigenic variation, where they alter their surface proteins to evade detection by the host's immune system, otherwise they may directly modulate host immune responses, either by suppressing immune function or by inducing inappropriate immune reactions that benefit the parasite (*Wakelin, 1996*).

In traditional diet choice modelling, researchers primarily focused on maximising net energy or protein intake as the principal objective of foragers (*Stephens & Krebs, 1986*). However, subsequent research introduced additional factors, including the risk of predation (*Milinski et al., 1978*), as well as the impacts of intraspecific (*Milinski, 1982*) and interspecific (*Millikan et al., 1985*) competition as significant contributors shaping an animal's dietary decisions.

However, in recent years, there has been an increasing recognition of parasites as another influential factor. The strategies that animals have adopted to avoid the spread of parasites can include three distinct mechanisms to influence diet choice.:

1. Dietary Modifications: Potential hosts may avoid consuming certain food items that are known to be common sources of parasites. This avoidance behaviour helps reduce the risk of parasite infection.
2. Prophylactic Measures: Animals may selectively consume certain food items in order to modify their internal environment, making it less hospitable to parasites. This proactive approach serves as a preventive measure against parasitic infestation.
3. Therapeutic Approaches: Certain foods may be deliberately chosen for their specific antiparasitic properties. These foods may contain compounds that have the ability to kill or expel parasites that are already established within the host's body, providing a therapeutic effect. (*Lozano, 1991*)

The last two adaptive behaviours fall under the concept of self-medication, wherein animals take proactive measures to protect themselves against parasitic challenges.

3.4.1 Microparasites

Microparasites include viruses, bacteria, protozoa and fungi, which pose a threat to the physiological integrity of living hosts, capable of infiltration, replication, and the initiation of pathological responses.

Their transmission occurs through various mechanisms. Viral or bacterial pathogens can spread through respiratory droplets released during coughing or sneezing or by direct contact with infected individuals or contaminated surfaces. Additionally, certain pathogens exploit biological vectors, such as insects, for their movement and colonisation. Environmental variables, including temperature and humidity, further influence the vitality and spread of pathogens.

In confronting this threat, the body depends on two fundamental defence mechanisms: immunologic defences, which involve the immune system's targeted responses against pathogens, and physical barriers like the skin and mucous membranes, which act as the first line of defence by preventing pathogen entry (*Loehle, 1995*).

A strong immune system can effectively combat infection, whereas immunocompromised conditions can predispose individuals to disease. Factors such as diet, hormonal balance, age, lifestyle choices, and even social isolation (*Sapolsky, 1994*) can influence the resilience of the immune system, thereby impacting the body's ability to fend off pathogens.

Hence, a critical factor in promoting robust animal growth and the subsequent establishment of a strong immune system is early exposure to pathogens. Young animals in the wild are regularly exposed to various microorganisms, which helps stimulate their immune system, potentially reducing the risk of autoimmune disorders in the future (*Engel, 2002*).

Furthermore, consuming maternal milk is essential for mammalian offspring as it provides tailored nutrition, including passive antibodies, immune system components, and medicinal compounds that enhance the infant's ability to combat infections (*Newburg et al., 1997*).

Otherwise, many animals exhibit a behaviour called coprophagy, where they consume faeces to supplement their gut microflora with essential bacteria. This behaviour is widespread across species like gorillas, elephants, rabbits, and hares, facilitating microbial diversity crucial for proper digestion and nutrient absorption, thereby fostering a healthy gut microbiome.

Secondly, natural selection has favoured animals that effectively avoid pathogen hotspots (*Loehle, 1995*), primarily through hygienic behaviours. These behaviours have undoubtedly provided advantages to certain individuals in terms of survival and reproductive success. For instance, Jane Goodall's observations in Gombe revealed chimpanzees' instinctive aversion to being soiled with excrement. When faced with such situations, they meticulously cleaned themselves using leaves (*Goodall, 1986*).

Similarly, honey bees exhibit remarkable hygiene by using tree resins to craft propolis, a coating that ensures a sterile hive environment. These hygiene practices likely contribute to the overall fitness and well-being of individuals exhibiting such behaviours.

When the initial defences against pathogens prove ineffective, animals have developed intricate strategies to aid their own protection. Some resort to the behavioural manipulation of body temperature, ensuring it remains elevated enough to harm pathogens but not excessively high to kill their own enzymes. Warm-blooded animals can passively regulate their body temperature, while cold-blooded creatures must actively induce fever by seeking warm locations or basking in the sun. Beyond elevating temperature, sunlight's ultraviolet (UV) rays alter the DNA of numerous microorganisms, rendering them incapable of reproduction. UV light is lethal for a wide range of pathogens, including bacteria, fungal spores, viruses, protozoa, nematode eggs, and algae.

Another immediate response to sickness is the avoidance of food through fasting. This deliberate reduction in food intake decreases the availability of iron, a vital element for bacterial survival. Alternatively, animals may opt for direct expulsion, inducing vomiting or diarrhoea to rid the body of potentially harmful substances (*Engel, 2002*).

Finally, the instinctive aversion to cannibalism in nature may also stem from an evolutionary imperative to avoid disease (*Pfennig et al., 1998*). One key reason is that pathogens have the remarkable ability to adapt and mutate in response to the conditions they encounter, so when a pathogen incubates within a conspecific host, it faces an environment that closely mirrors its own genetic makeup. This intimate connection allows the pathogen to potentially evolve more efficiently, becoming better adapted to the specific host species. Consequently, the pathogen may pose a greater threat when transmitted within a population of conspecifics compared to those incubated in the body of a different species.

3.4.2 Macroparasites

3.4.2.1 Ectoparasites

Ectoparasites are organisms that live on the external surface of their host and include various insects and mites.

First line of defence is fidgeting, twitching, and constant movement, which are effective ways to evade bites from parasites such as fleas, ticks, and flies. Otherwise, some species take advantage of specific weather conditions, for instance, feral horses seek windy hills to escape bothersome flies, tigers commonly immerse themselves in water and Malawi elephants carry bunches of palm leaves in their trunks to swat away flies. Moreover, large mammals like elephants, buffalo, and rhinoceroses roll in thick mud, forming a protective barrier against parasites (*Engel, 2002*).

Secondly, maintaining healthy skin is crucial, and animals employ various methods to achieve this. Birds, for instance, bathe in dust, which absorbs excess oils from their feathers and dries the skin surface, making it less hospitable to microorganisms. The soil contains tiny, sharp particles that can cut the exoskeletons of small parasites, further aiding in defence.

Additionally, many animals bask in the sun , which not only dries out their plumage or fur but also has positive effects due to exposure to ultraviolet light (*Moyer et al., 2001*).

Salt is another commonly used remedy for skin issues, as its osmotic properties can burst microorganisms and ectoparasite larvae. For example, camels often roll in natural salt pans to alleviate skin conditions.

Ultimately, urine washing was observed in wild moustached tamarins, native to the rainforests of South America (*Heymann, 1995*). While the exact reasons for this behaviour are not fully understood, researchers have proposed several hypotheses. One explanation is that urine washing could serve a hygienic function by helping to remove parasites or bacteria from the tamarin's fur. Otherwise, since urine contains urea, a compound with antibacterial and antifungal properties, tamarins may be using it as a natural disinfectant. This hypothesis is supported by the fact that the medical community recognizes urea's efficacy in wound treatment, often employing it as a cooling disinfectant to combat infections.

Anointing behaviours and Fur rubbing

Birds and mammals dedicate a significant amount of time to tending to their skin, fur, or feathers, primarily through grooming. This involves activities like licking, scratching, preening, or rubbing different body parts with the mouth, tongue, beak, or limbs to keep themselves clean and healthy.

However, there are also more specialised behaviours where animals employ medicinal strategies. For example, the European hedgehog, which is vulnerable to fungal infections and parasites due to its spiky exterior, often anoints itself with pungent substances like mint, tobacco oil, or fermenting fruit to protect itself (*D'Havé et al., 2005*).

Similarly, white-nosed coatis engage in anointing behaviour by rubbing resin from the *Trattinnickia aspera* tree into their coats. This resin, with its menthol-like odour, is obtained by rupturing resin ducts in the tree base. The coatis then vigorously groom the resin over their entire bodies, including their tails and faces (*Gompper et al., 1993*).

In primates, anointing has been recorded in black lemurs with toxic millepedes, black-handed spider monkeys with the leaves of aromatic tree species, orangutans with Commelina herbs, golden-headed lion tamarins with tree exudates and owl monkeys with plants and millipedes

(*Birkinshaw, 1999; Campbell, 2000; Morrogh-Bernard, 2008; Guidorizzi & Raboy, 2009; Zito & Weldon, 2003*).

Digging deeper, wild and captive capuchin monkeys apply a variety of substances onto their fur, which share common characteristics. Firstly, they tend to choose items with pungent scents, such as citrus, piper plants, tobacco, onion, garlic, alcohol, ants and millipedes. Secondly, they select substances that have stimulating effects when rubbed onto their fur, including citrus juice, Clematis (a rubefacient), and ice.

During anointing, these monkeys typically bite and roll a plant between their hands while applying the resulting plant-saliva mixture over their entire skin. Citrus fruits are particularly favoured, with the monkeys breaking open the fruit and hugging it to their chests to transfer the juices onto their skin.

Fig. 10 Adult male applying Citrus juice over his body. He has pounded the fruit on the tree and is digging into it. He will then apply the juice over his body using his hands, feet, and tail.

Although the exact intent behind this behaviour is not fully understood, it may not necessarily be for medicinal purposes. Instead, the scents of these plants may serve to establish a group scent, similar to other forms of scent marking observed in primates; or, social fur rubbing during anointing may reinforce social bonds among individuals (*Bowler et al., 2015*). Alternatively, the monkeys may simply enjoy interacting with the plant material, similar to how cats respond to catnip.

However, anointing behaviour in primates is often proposed to serve as a form of self-medication against skin parasites or as a repellent for flying hematophagous insects because many of the substances that are used to anoint have properties that repel insects or have antimicrobial effects. For example, benzoquinone secretions from millipedes repel insects and ticks, formic acid from ants repels tick nymphs, Piper plant leaves are traditionally used in Latin America to treat skin conditions, onion contains effective antimicrobial agents, and citrus fruits contain volatile oils and flavonoid glycosides with analgesic, insecticidal, and antimicrobial properties. Furthermore, wild capuchin monkeys anoint more frequently during the wet season when there is an increased presence of flying insects.

Fur rubbing among mammals isn't just about keeping pests at bay; it also serves to alleviate discomfort. When animals rub their fur with substances that have astringent and analgesic properties, it provides quick relief from itching and sores. This dual action not only helps prevent skin issues but also aids in the treatment of existing ones, offering both curative and preventive effects.

Nesting material

The nests of birds and the burrows and dens of mammals serve as breeding grounds for diseases and ideal locations for ectoparasites due to their dark, moist, and warm environments.

Some animals are forced to leave nesting colonies and relocate when infestation levels become too high. Veterinarian Benjamin Hart suggests that this phenomenon may have contributed to the evolution of migrations as a survival strategy against disease and infestations.

Others have developed intelligent strategies to cope with infestations without the need to relocate. For instance, the European badger exhibits a behaviour of switching nest chambers as the number of parasites builds up. Each badger is careful not to sleep in a chamber used the previous night by another badger, minimising the risk of parasite transmission. Apart from airing out their bedding, European badgers also gather fresh green foliage such as bluebell and daffodil leaves, wild garlic, ground elder, and other botanicals, notable for their aromatic, antimicrobial, and insecticidal properties, thereby creating a hostile environment for parasites and reducing infestation rates. The badgers predominantly gather these materials during times of vulnerability, notably when nurturing their youngs (*Neal et al., 1996*).

This behaviour was also observed in at least 50 species of birds, known to incorporate fresh plant material into their roosting environment that are not part of their nest structure (*Raman & Kandula, 2008*). These plants contain volatile secondary compounds that studies have shown to be effective in reducing the hatching success of bird lice and inhibiting bacterial growth.

Fig. 11 Male European starling line the nest with fresh aromatic herbs

European starling birds exhibit a selective preference for plants with complex aromas, such as wild carrot, yarrow, agrimony, elm-leaved and rough goldenrod, and fleabane, even when they are not the most common plants nearby (*Fauth et al., 1991*). This behaviour of bringing greenery to the nest is not only a means of enhancing hygiene but also serves as part of the male's courtship display. Females indeed, use the presence of these herbs as an indicator of the male's health and vitality, thus influencing mate selection. Furthermore, it has been demonstrated that the herbs selected by starlings contribute to the overall health and well-being of their chicks, perhaps by enhancing the immune system (*Gwinner et al., 2000*).

3.4.2.2 Endoparasites

The lifecycle of an endoparasite typically begins with its entry into the host's body, facilitated by ingestion or penetration of the skin. Once inside, the parasite employs various strategies to evade the host's immune system while moving through the body.

Established within the host, they undergo crucial developmental stages, including growth, reproduction, and adaptation to diverse host environments. These stages are vital for the parasite's survival and lifecycle completion.

These parasites depend on the host for nutrients, often inflicting harm to tissues and organs in the process. Consequently, hosts may experience a spectrum of health issues, ranging from mild discomfort to severe illness or even fatality. Interestingly, although free-ranging wild animals usually carry some parasites, they rarely show ensuing symptoms.

Animals inherently possess mechanisms to prevent their living spaces from becoming contaminated with potential parasites (*Hart, 1990*), for example sheep, cows, horses, rabbits, and numerous other species actively avoid grazing near faecal matter or establish designated latrine areas away from their food sources; while, large mammals that use dens (e.g. foxes, bears, wolves) generally defecate outside the burrow. Similarly, yellow baboons adjust their sleeping branches based on the accumulation of faecal contamination, returning to the same spot only once beetles have consumed all the faecal matter (*Engel, 2002*).

Nature's pharmacy offers numerous anthelmintic plants, which often rely on their inherent toxicity for effectiveness. These plants may be consumed as part of an animal's regular diet or specifically ingested in response to parasite presence.

In the former scenario, the astringent properties of tannins, found in many plants regularly consumed by various animals, play a crucial role. Tannins bind to the proteins that make up intestinal parasites, rendering them harmful; for instance, when domesticated goats are fed polyethylene glycol to deactivate tannins in their diet, the number of intestinal parasites increases (*Kabasa & TerMeulen, 2000*). Similarly, red deer in New Zealand that feed on tannin-rich plants, such as chicory, require less chemical dewormer (*VerheydenTixier & Duncan, 2000*).

On the other hand, animals may employ different methods of worm control. One well-documented instance of putative self-medicative behaviour in great apes is the leaf-swallowing behaviour observed in Gombe chimpanzees. This behaviour involves the slow and deliberate swallowing of whole leaves that are folded between the tongue and palate, passing through the gastrointestinal tract visibly unchanged (*Huffman & Caton, 2001*). These primates have been observed feeding on *Aspilia pluriseta* leaves, which contain the chemical Thiarubin-A, known for its antibacterial, antifungal, and anthelmintic properties (*Rodriguez E et al., 1985*).

Leaf-swallowing behaviour is widespread among African great apes, including chimpanzees, bonobos, and lowland gorillas, who utilise a variety of plant genera, represented by more than thirty-four species (*Huffman, 1997*). The common feature among these plants is their lack of apparent nutritional value and their rough texture. As a result, the primary mode of action is physical, mechanically expelling parasites that freely roam within the large intestine and that become trapped on the surface of the leaf.

Additionally, the rough leaves stimulate diarrhoea and increase gut motility, aiding in the expulsion of worms and potentially their toxins from the body. Leaf swallowing is typically observed at the beginning of the rainy season when nodular worm infestations increase, and many leaf-swallowing apes experience diarrhoea, malaise, and abdominal pain.

However, apes are not the only species to utilise this method of worm control. Alaskan brown bears in Katmai National Park consume high-fibre, sharp-edged sedge (*Carex spp.,* Cyperaceae) a few months before hibernation, which apparently scrapes out worms (*Engel, 2002*).

A more common example is seen in domestic dogs and cats, which eat grass when sick due to intestinal parasites. Different types of grasses may serve different medicinal functions, with hairy grasses acting as emetics and couch grass as purgatives.

Revisiting the idea of using toxicity as a form of treatment, another approach involves seeking out plants with a bitter taste, as bitterness often signifies toxicity, which on the other hand means medicinal properties. Engaging in bitter-pith chewing fulfils all the criteria for self-medication: a sick animal actively seeks out a seldom-used plant with minimal nutritional value, consumes it in an unconventional manner, persists in this behaviour while unwell but ceases once recovered, and experiences improvement within a reasonable timeframe. Additionally, the plant contains compounds capable of exerting medicinal effects, and the animal consumes a potentially therapeutic dose.

Vernonia amygdalina, renowned for its intense bitterness, represents the most bitter plant accessible to chimpanzees in the forest, which they have been observed to consume. Its taste is attributed to the sesquiterpene lactones (previously known to chemists as “bitter principles”) found in numerous Vernonia species. Pharmacological investigations have revealed a diverse range of biologically active properties within V. amygdalina (*Yeap, 2010*), like anthelmintic effects against parasites such as Oesophagostomum, Toxicara, Ancylostoma, Schistosoma, and Entamoeba, as well as properties inhibiting tumour growth (*Adedapo, 2007*). Furthermore, this species boasts numerous applications in treating ailments affecting both humans and livestock (*Egharevba, 2014*).

Despite their usual avoidance of this plant, chimpanzees may alter their eating habits or tolerance levels during sickness. When ingesting the pith from the young shoots of V. amygdalina, chimpanzees meticulously remove the outer bark and leaves to chew on the exposed pith, extracting the bitter juice and residual fibre.

Chimpanzees do not necessarily need to comprehend their worm infestation to engage in self-medication; rather, they probably respond to gastrointestinal discomfort by associating relief with bitter-pith chewing or leaf swallowing.

Fig. 12 Bitter pith chewing of Vernonia amygdalina (left) and leaf swallowing (right) of Aspilia mossambicensis.

Consuming earth, or clay, represents another traditional method employed by various animal species to combat intestinal parasites. Clay serves a multifaceted role in addressing parasitic infestations: it can absorb toxins secreted by the parasites, physically expel worm eggs, and shield the gut from invasion by migrating worm larvae (*Engel, 2002*).

Furthermore, the practice of eating clay appears to offer both curative and preventive benefits against parasite infections (*Knezevich, 1998*). Research suggests that consistent consumption of soil over an extended period leads to a thickening of the gut wall, which serves as a barrier against parasitic invasion. Consequently, older individuals, who have consumed clay over time, tend to exhibit fewer parasites than younger ones.

4. Case Study

In this experiment, I aimed to investigate the fur rubbing behaviour of capuchin monkeys, following existing literature on the subject. Fur rubbing, a notable behaviour observed in various primate species, involves the act of monkeys rubbing or stroking objects or substrates against their fur. This behaviour has been suggested to serve multiple functions, including social bonding, self-grooming, and territorial marking.

The experiment could also have positive implications for the monkeys under examination, aiming to improve their quality of life by exploring more natural, cost-effective, and sustainable methods for parasite control, thereby contributing to their welfare and well-being.

4.1 Materials and Methods

This study involved observing two female capuchin monkeys, approximately 11 years old, residing in a spacious 6x7x5-metre enclosure at the Los Jaguares Rescue Center in Ecuador. The enclosure was adorned with natural vegetation and various structures for climbing and hiding.

These two capuchin monkeys belonged to different species within the order Primates and the family Cebidae. The first, *Cebus albifrons*, exhibited a lively and curious disposition, demonstrating behaviours closely aligned with its natural tendencies. She spends a significant amount of time exploring the enclosure, hunting insects, foraging, and unfortunately, pacing back and forth along the bamboo structures. Despite this behaviour, she enthusiastically interacts with any enrichment provided to her.

In contrast, the second, a *Sapajus apella*, displayed a more tranquil and solitary temperament, showing a preference for seclusion. She spends most of her time in the hidden areas of the enclosure, which include a wooden little house and an attic with a wooden box. She is often seen lying down and does not particularly interact with the keepers.

Their daily routine consists of two meals, one in the morning at 9:30 a.m. and the other in the afternoon at 3:30 p.m., during which they are also provided with enrichments such as a hollow bamboo filled with honey or peanuts that they must extract from special holes. Water is always available in a large bowl where they can also immerse themselves, and it is regularly changed. During the remaining time, they are free to act as they prefer, although they may be disturbed by visitors from the centre or keepers entering the enclosure for cleaning purposes.

Their daily diet at the centre consisted of bananas, papayas, and corn, supplemented with a rotating variety of foods such as eggs, grapes, granadilla, apples, sugar cane, mangoes, and insects, depending on availability and dietary considerations.

Fig. 13 The Cebus albifrons (left), the Sapajus apella (centre), the enclosure (right)

For the experiment, the foods used were not part of their regular diet and consisted of: red onion, garlic, mandarin, lemon, orange, and mint leaves, readily available at the local market. Citrus fruits were presented in two forms: sliced in half and only the peel.

The experiment consisted of offering a small, harmless amount of each food item individually, one per day, starting one hour after their morning meal, specifically at 10:30 a.m.

The purpose was to observe the monkeys' initial reactions to each food item presented for the first time, taking into account existing literature on their natural behaviours and preferences.

The data collection method employed is known as one-zero sampling, which involves breaking down the 30-minute time interval into 10-minute segments. Within each segment, if the animal demonstrates the specified behaviour at least once, it is recorded as "1"; otherwise, if the behaviour does not occur, it is recorded as "0".

It's crucial to note that the two monkeys are considered individually in the data collection process, enabling a comprehensive analysis of their behaviours.

The behaviours under study include:

- Rubbing: The monkey rubbing or stroking the object against its fur. It may include vigorous rubbing motions, often accompanied by vocalisations or facial expressions indicative of pleasure or comfort.
- Ingestion: The monkey actively takes the object into its mouth and chews or swallows it.
- No interaction: The monkey does not interact with the object in any way.

4.2 Results

Cebus albifrons	Rubbing			Ingestion			No interaction		
Intervals	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Red onion	1	1	0	0	0	0	0	0	1
Garlic	1	1	0	0	0	0	0	0	1
Mandarin half	0	0	0	1	0	0	0	1	1
Mandarin peel	1	0	0	0	0	0	0	1	1
Lemon half	0	0	0	1	1	0	0	0	1
Lemon peel	0	0	0	0	0	0	0	1	1
Orange half	0	0	0	1	0	0	0	1	1
Orange peel	1	0	0	0	0	0	0	1	1
Mint leaves	0	0	0	0	0	0	0	1	1

Sapajus apella	Rubbing			Ingestion			No interaction		
Intervals	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Red onion	1	1	0	1	1	0	0	0	0
Garlic	1	1	0	1	1	0	0	0	1
Mandarin half	0	0	0	1	1	0	0	0	0
Mandarin peel	1	0	0	0	0	0	0	0	1
Lemon half	0	0	0	1	1	0	0	0	1
Lemon peel	0	0	0	0	0	0	0	1	1
Orange half	0	0	0	1	1	0	0	0	1
Orange peel	1	0	0	0	0	0	0	0	1
Mint leaves	0	0	0	0	0	0	0	1	1

Notably, both monkeys displayed a strong interest towards onions and garlic, engaging in extended fur rubbing behaviour upon encountering these food items. However, the Sapajus apella exhibited an additional level of interaction by ingesting both onions and garlic.

In the case of citrus fruits, the monkeys predominantly chose ingestion when presented with the flesh, while reserving fur rubbing exclusively for the peel, particularly of the mandarin's one.

Interestingly, neither monkey showed any inclination towards the mint.

Fig. 14 Cebus albifrons biting (left) and rubbing (right) a piece of onion.

4.3 Conclusions

The observation of fur rubbing behaviour persisting in captive-born and raised monkeys suggests an inherent, possibly genetically driven propensity for this behaviour among capuchin monkeys, regardless of their rearing environment.

Furthermore, the monkeys' preference for pungent foods like onions and garlic for fur rubbing contrasts with their wild conspecifics, who typically favour citrus fruits for this behaviour. The absence of onions and garlic in their natural environment raises intriguing questions about the impact of captivity on behavioural adaptations. Alternatively, it could be that both wild and captive capuchin monkeys are naturally drawn to items with strong odours, regardless of their availability in the wild.

Finally, it's important to note that this study is confined to the specific context in which it was conducted, limiting the applicability of the results solely to the monkeys under investigation. The limited number of subjects and research methods used, which have significant limitations including the lack of test repetition, variable climatic conditions, and disturbances from sources like tourists, do not ensure the validity and generalizability of the findings to other contexts. Therefore, while my insights into fur rubbing behaviour in capuchin monkeys may provide valuable contributions to understanding their behaviour and welfare, further in-depth research is necessary if one intends to propose this research as a supportive source for future field applications.

In conclusion, this experiment was unfortunately unable to bring about any changes in the health status of the capuchin monkeys residing at Los Jaguares Rescue Center. This is because, despite both monkeys showing a strong response to fur rubbing with both onion and garlic, the fact that the Sapajus apella ingested both substances after using them and that they can be toxic to this species if consumed regularly, impedes the idea of using these foods as a regular antiparasitic treatment.

5. Conclusions

5.1 Captive Animals

"Animals in captivity, unable to range freely over their natural habitat, rely on humans for their health care. Sadly, we often fail to do an adequate job, but applying what we have learned about wild health can greatly improve this situation" (*Engel, 2002*).

Captivity imposes significant challenges on wild species, leading to numerous health issues and psychological disturbances, like stereotypical behaviours, self-abuse, or even a catatonic state. Additionally, physical health deteriorates due to the denial of access to essential elements such as soil, microorganisms, climate, weather conditions, social interactions, and wound tending, crucial components to which these animals are adapted in their natural habitats. Moreover, captive animals are exposed to new pathogens against which they have no resistance, and, unlike their conspecifics in the wild, they cannot move away from pathogen hotspots nor avoid potentially violent interactions with other animals. To provide just a few examples, nearly half of zoo gorillas succumb to cardiovascular diseases, captive elephants commonly suffer from foot problems and arthritis, and the hemolytic anaemia responsible for the deaths of 75% of captive black rhinoceroses is entirely absent in their wild counterparts (*Fowler, 1993*).

Furthermore, the diets provided in most zoos are often based on traditional practices rather than specifically designed to meet the nutritional and non-nutritional needs of individual animals. The Asian elephants for example are routinely fed a diet extrapolated for the nutritional needs of a large horse.

As mentioned earlier, these needs can vary depending on factors such as health status, reproductive state, age, and social environment. While animals in the wild may instinctively seek out specific foods to address their nutritional requirements, those in captivity are deprived of this choice.

Traditional medicines are not yet considered integral components of captive animals' requirements, this means that animals may not have access to potential remedies that could alleviate their health issues. By understanding how animals in the wild naturally seek out and utilise medicinal substances to maintain their health, researchers can develop targeted strategies for improving the well-being of captive animals, for example by incorporating elements of self-medication into captive environments, such as specific plants or materials with medicinal properties.

The Apenheul Zoo in the Netherlands serves as an exemplary case study. After determining that many woolly monkeys (*Lagothrix lagotricha*) suffered from dietary hypertension, which often led to kidney and liver failure in captivity, a variety of medicinal plants were introduced into the enclosure. Zookeepers noticed that, after conflicts or fights, many of the monkeys began to consume valerian (*Valeriana officinalis*), an herb known for its calming effects and ability to lower blood pressure. Other than valerian, the plants reported to be used are several common European herb species noted for their activity against stress (wild chamomile, catnip and lavender), hypertension (garlic and hawthorn) and bladder infection (common berberry and fennel)(*Vermeer, 1995*).

5.2 Wild Animals

Observations of wild animal health play a pivotal role in safeguarding endangered species. While captive breeding programs effectively preserve individual species, they often lack in maintaining the natural connection between animals and their environment (*Lozano, 1998*). In fact, despite decades of international conservation efforts, only a handful of reintroduction programs have achieved success.

One of the primary challenges lies in assisting reintroduced animals in adapting to unfamiliar and ever-changing environments. They must learn to secure adequate nutrients, avoid potential toxins, navigate pathogen hotspots, and manage parasitic infections—skills that captive-raised animals may lack.

The concept of self-medication adds another layer of complexity to the reintroduction process. Wild animals instinctively seek out medicinal plants or substances to maintain their health, however, animals raised in captivity may not have acquired these self-medicating behaviours. Consequently, they may struggle to acclimate to their new surroundings, heightening the risk of reintroduction failure.

In essence, understanding how animals maintain their well-being in the wild is crucial for successful reintroduction efforts. By comprehending the resources necessary for their health, conservationists can ensure that protected areas offer adequate support for survival. Moreover, by ensuring that released animals have acquired essential behaviours, such as locating medicinal plants or avoiding harmful substances, their chances of successful reintroduction into their natural habitat can be significantly enhanced.

5.3 Farm Animals

In the pursuit of maximising productivity, farm animals, particularly in the poultry industry, have been bred for rapid growth and efficient meat production. However, this focus on productivity often comes at the expense of the animals' health and welfare. Poultry breeds have been selected to reach market weight in as little as forty days, which is a remarkable feat of genetic engineering. Nevertheless, this accelerated growth puts immense stress on the birds' bodies. As chickens grow rapidly, Their muscles develop too quickly, without allowing sufficient time for the development of their circulatory and cardiac systems. Consequently, these birds often suffer from circulatory problems and heart failure due to the excessive muscular load. Additionally, their skeletal systems are unable to support the rapid muscle growth, leading to 80% of broilers experiencing broken bones or other skeletal defects (*Farm Animal Welfare Council, 1999*).

Furthermore, the diet provided to these birds is often formulated by computer programs, optimising for cost rather than nutritional quality. This "least cost formulation" calculates the cheapest ingredients that meet basic nutrient requirements, which can include unconventional ingredients like ground-up feathers, banana skins, or even chicken carcasses.

To compound these issues and further enhance growth rates, feed is supplemented with antibiotics, which elevate use can pose significant risks to human health, contributing to the emergence of antibiotic-resistant bacteria and potentially harmful residues in meat products.

In response to this challenge, exploring natural remedies and traditional practices, such as self-medication observed in nature and traditional diets incorporating herbal medicines, offers a promising alternative.

Chicken farmers can draw valuable lessons from the natural health behaviours observed in wild red jungle fowl populations. These birds, living in forest environments, exhibit a range of practices that contribute to their well-being. They form small social groups, engaging in activities like dust-bathing and sunning their feathers to maintain cleanliness and health. When it rains, they instinctively preen themselves, ensuring their feathers remain in optimal condition. Furthermore, red jungle fowl forage on the forest floor, consuming a varied diet of insects, worms, and fresh greens, which helps them balance their nutrient intake according to their needs.

However, farming conditions often lack the ability to provide chickens with what they truly need for optimal health. Simple measures such as access to sunlight, or allowing chickens the opportunity to choose their food could significantly impact their well-being, potentially reducing the reliance on medications.

In 2000, in Kentford, a distressing incident occurred where twelve hundred chickens died due to heatstroke (*Engel, 2002*). Subsequent research on self-medication in animals highlighted an interesting finding: supplementing with vitamin C could potentially increase heat resistance in chickens. The challenge arose when considering how to administer this supplement safely, since providing extra vitamin C to chickens not under stress could lead to unintended health issues. Consequently, farmers were hesitant to administer it as a supplement, fearing adverse effects.

However, it was demonstrated that if the option to consume vitamin C had been presented to the chickens themselves, they naturally adjust their intake according to their needs, for example during times of heat stress, chickens instinctively increase their consumption to help them cope with the adverse conditions (*Kutlu & Forbes, 1993*).

An example that has fortunately succeeded in improving husbandry practices following an observation of self-medication is the case of prolonged scouring (diarrhoea) in cattle. When a cow fell ill with prolonged scouring, ranchers noticed that the sick cow would leave the enclosure and return after a few days, fully recovered. Upon investigation, it was discovered that these animals sought out clay barks and consumed clay until their health was restored (*Mahaney, et al., 1996*). Recognizing the significance of this behaviour, ranchers began transporting clay to their livestock as a preventive measure, a practice that continues to be followed today. In some instances, barn-reared cattle inadvertently ingest clay when it is used as a binding agent in cattle pellets, while in regions such as North America, cattle are routinely supplemented with bentonite clay to mitigate gastrointestinal issues.

This example highlights the importance of observing and understanding self-medication behaviours in animals, as it can inform proactive measures to promote animal health and reduce reliance on antibiotics and anthelmintics. By embracing traditional knowledge and natural remedies, livestock management can move towards more sustainable and holistic approaches that benefit both animal welfare and human health.

5.4 Hopes and Opportunities

The interdisciplinary fields of ethnomedicine, ethnoveterinary medicine, and ethnopharmacology explore traditional knowledge of medicinal plant use and animal self-medication behaviours to seek alternative treatments for human and livestock diseases, especially in response to increasing resistance to synthetic drugs (*McGaw et al., 2020*). These treatments, found to be consistently effective, have become widely accepted as complementary health care treatments even in industrialised nations (*WHO, 2019*).

Moreover, by bridging the gap between traditional ethnomedical knowledge and contemporary biomedical research, zoopharmacognosy presents a holistic approach to drug discovery. The challenge of identifying plants with potential medicinal properties has long been a significant impediment in the field, with traditional methods relying on laborious screening processes and chance discoveries. The study of self-medication among animals provides a unique opportunity to address this challenge: by observing and investigating the natural remedies employed by animals, researchers can glean valuable insights into the pharmacological properties of various plants. This approach not only offers a better understanding of how organisms interact with their environments, but also makes it easier to find potential medicinal compounds, for example the study of chimpanzee bitter-pith chewing has already led to the discovery of 11 bioactive constituents in a new group called the steroid glucosides (*Ohigashi et al., 1994*).

Furthermore, the research into self medication in great apes can be expected to provide equally viable sources of natural products for the effective treatment of parasitosis, a prevalent health concern in human, domestic and captive animals (*Berry et al., 1995*).

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Image bibliography

Tab. 1 Huffman MA. Folklore, Animal Self-Medication, … Planta Med 2022; 88: 187–199 | © 2021. Thieme.

Tab. 2 Jain, C. P., Dashora, A., Garg, R., Kataria, U., & Vashistha, B. (2008). Animal self-medication through natural sources. Natural Product Radiance, 7(1), 49-53.

Fig. 1 https://www.treesandshrubsonline.org/articles/juglans/juglans-nigra/

Fig. 2 https://www.peruaves.org/macaw-and-parrot-clay-licks-in-peru/

Fig. 3 https://scitechdaily.com/two-millipede-species-appear-to-have-a-treaty-in-the-form-of-a-demilitarized-zone/

Fig. 4 https://hikingmichiganandbeyond.com/2019/10/02/backpacking-isle-royale/

Fig. 5 Photo by Kristi Odom, Colorado Pika Project, Special to The Colorado Sun. https://coloradosun.com/2023/08/27/colorado-pika-population-climate-change/

Fig. 6 https://azbirds.com/products/great-blue-turaco

Fig. 7 https://wwf.panda.org/wwf_news/?242040/Ongoing-efforts-to-support-Dzanga-Sangha-wildlife

Fig. 8 https://blogs.library.duke.edu/data/2022/10/31/the-duke-research-data-repository-celebrates-its-200th-data-deposit/

Fig. 9 https://commons.wikimedia.org/wiki/File:Lioness_%28Panthera_leo%29_licking_her_wounds_..._%2830862486525%29.jpg

Fig. 10 Baker, M. (1996). Fur Rubbing: Use of Medicinal Plants by Capuchin Monkeys (*Cebus capucinus*). American Journal of Primatology, 38263-270.

Fig. 11 Gwinner, H., Oltrongge, M., et al. (2000). Green plants in starling nests: Effects on nestlings. *Animal Behaviour*, 59(2), 301-309.

Fig. 12 Huffman, M. A. (1997). Current Evidence for Self-Medication in Primates: A Multidisciplinary Perspective. Yearbook of Physical Anthropology, 40, 171-200.