Journal of Animal Physiology and Animal Nutrition

DOI: 10.1111/jpn.12103

REVIEW ARTICLE

The diet of adult psittacids: veterinarian and ethological approaches

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Summary

Parrots species are kept as pets because of their colours, their vocal abilities, their longevity and also their behaviours. Nevertheless, many owners do not know how to feed their bird in a healthy way and sometimes veterinarians and ethologists are confronted to dramatic situations. Diet is a key factor to prevent and reduce health and psychogenic disorders. Imbalance can lead to physical, physiological and behavioural modifications that can weaken the owner–bird relationship, cause bird discomfort and sometimes threaten its survival. Psittacids are known for their complex cognitive and communicative abilities. They are social animals and need many interactions. Kept in captivity, they could suffer from boredom because of lack of stimulations and also because of lack of possibility to explore and to forage, which could represent up to 70% of their day time in the wild. Indeed, humans control every parameter in the environment of pet psittacids. They provide a highly digestible diet. In captivity, foraging is not mandatory, and the bird can get bored. Here, we present a review of the literature regarding the quality of the diet and health disorders on one hand and the interaction between foraging opportunities and psychogenic disorders in adult psittacids on the other hand.

Keywords psittacids diet, health prevention, psychogenic disorders, cognition, welfare

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Received: 6 November 2011; accepted: 13 June 2013

Introduction

Over 330 makes up the family Psittacidae, including parrots, parakeets, parrotlets, macaws, lovebirds, loris, and lorikeets (Homberger, 2006). The following review will exclude nectarivore and frugivore species. Some of these psittacids species are kept as pets and are seen in exotic animal veterinary practice. Many people are attracted by these species because of their physical characteristics and mainly because of their cognitive and communicative abilities (Pepperberg, 1999; Péron, 2012). Indeed, they are able to learn and imitate human words and use them in appropriate situations (Pepperberg, 1999; Giret et al., 2009, 2010). They are colourful clowns that use their beak as a third foot and play most of the time. Parrots and parakeets represent a new market for food industry and accessory shops. It is clear that a parrot represents a great investment in time and money as they live several decades. Products offered in shops are quite reassuring for people because their bird will like it. Indeed, psittacids like humans do not select food to promote health but only to experience pleasure when consuming it and follow habits (Koutsos et al., 2001; Kalmar, 2011). Furthermore, the way the food is provided does not always respect the natural behavioural repertoire of the animals. Thus, veterinarians and ethologists face dramatic situations where bird welfare and sometimes survival are threatened. Hess et al. (2002) surveyed owners of psittacid birds and found that several birds had inadequate intakes of vitamin A and D3 and calcium (when fed with seeds or human food); excessive fat intake (when fed with seeds) or low protein and energy intake (when fed with human food). Manifestation of resulting deficiencies remains subclinical for prolonged periods of time, and when clinical symptoms do emerge, they are often unspecific and remain undiagnosed (Wolf et al., 1998). As the diet influence directly the life span (Munshi-South and Wilkinson, 2006), here we provided some elements to improve psittacids' captive diet and thus human–bird interactions. After a short review of veterinary knowledge, ethologic results will be presented.

Veterinarian perspectives

Feeding of birds is one of the most challenging aspects of their care, primarily because of limited specific nutritional experimental studies on each species (Koutsos et al., 2001; Harrison et al., 2006). Most neotropical parrots inhabit closed-canopy forests, which renders research on their natural diet very difficult and incomplete (Gilardi and Munn, 1998). Nutritional status of companion birds is known to influence not only their physical appearance but also their immunity and reproductive success (Koutsos et al., 2001).

Determination of bird nutrient requirements

Bird nutrient requirements vary depending on species, age and physiological status (breeding, maintenance, illness, etc.) (Brue, 1994; Koutsos et al., 2001). More and more publications about psittacids' nutritional requirements are available (see Kalmar et al., 2010b for a review) but because of the extreme difficulty in accurately determining the requirement of all nutrients, even for a single species, the trace nutrient requirements established for poultry remain, by default, as the standard (Koutsos et al., 2001). However, results to date indicate that the energy, protein and calcium requirements are lower in psittacine birds than in poultry (Koutsos et al., 2001). It is now well established that seed mixes are not a balance diet, and that improving diet in a short term during moulting or egg laying is not a good practice (Harrison et al., 2006). Feeding should be optimal year round. Some breeders choose the diet depending on the bird preferences. However, animals do not exhibit 'nutritional wisdom' when selecting dietary ingredients (Koutsos et al., 2001). For example, egg-laying kakapo hens select a diet that apparently is deficient in essential fatty acid even when foods that can meet the requirement are available (Body and Powlesland, 1990). Birds have individual preferences for foods based on taste, habits, food placement, texture, size, shape and colour (Brue, 1994; McKenzie and Whittingham, 2010). Avian taste buds are found in much lower numbers than those of mammals in the oral cavity. Parrots have been reported to have 350 taste receptors, compared with 9000 in humans (Berkhoudt, 1985). However, studies in cockatiel suggest that their gustatory abilities depend on the compound being tested: they appear to be insensitive to three common sugars (sucrose, fructose and glucose) (Matson et al., 2000, 2001) but reject salts around the point of osmolarity (Matson et al., 2001) and plant secondary compounds (quinine, gramine, tannins) with thresholds ranging from 0.1 to 10 μM (Matson et al., 2004). These findings support the hypothesis that cockatiels use taste to detect, monitor and possibly avoid intake of potentially toxic compounds. A recent study reports that even if parrots try to avoid toxic plants, they are able to cope with it (Gilardi and Toft, 2012). Geophagy–ingestion of clay or charcoal for example–is one of the defence mechanism against secondary toxic plant compounds (Burger and Gochfeld, 2003; Mee et al., 2005) adsorbing potential dietary toxins and possibly conferring cytoprotection of the gastrointestinal lining (Collar, 1997; Gilardi et al., 1999).

The preferences for some specific type of food (seeds mainly) can be strong, and some owners encourage them by providing what the bird is most likely to readily eat. When given the choice, birds often choose seed mixes (Kalmar et al., 2008a). This type of limited feeding pattern, like 100% sunflowers or peanuts, can result in severe deficiency. Providing a large variety of foods immediately pre- and post-weaning is a very effective way to develop good eating habits that will tend to persist throughout life (Brue, 1994).

Imbalanced seed mixes and over-supplementation

There is a general perception that fresh is better. However, seed mixes (edible part) are not a balanced diet because they lack vitamin A, D, K, E and calcium, and they are too rich in fat (Wolf, 2002; Harrison et al., 2006). Much of the product is sold in its immature state of growth, and even when matured, it does not provide the same nutrient profiles as wild seeds. Many seeds contain appropriate total protein, but lack essential amino acids like lysine and methionine (Roudybush and Grau, 1985). Determination of specific fatty acid dietary requirements has been undertaken on some granivorous species. In contrast to fatty acid profiles of commercial grains, fatty acid composition of wild seeds is characterized by a lack of ω-6 fatty acids (McDonald, 2004a). Even for granivore species, a standard commercial grain can be considered an imbalanced diet because seeds from domestic plants are more concentrated in energy and lower in protein and many other nutrients than seeds available in the wild (Klasing, 1998). Formulation of species-specific seed mixtures is largely based on the size of seeds in relation to the beak size and on experience as regards dietary preferences of the species, rather than on species-specific nutrient requirements (Kalmar, 2011).

While breeders and owners currently supplement drinking water with vitamins and minerals, this is not recommended. Indeed, water intake varies among species, individuals and is influenced by

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environmental temperature and diet (Koutsos et al., 2001). Some vitamins such as vitamin A and C are light sensitive (Harrison et al., 2006), and in aqueous solution, many vitamins are destroyed because of the high redox potential of minerals, especially iron, zinc and copper (Koutsos et al., 2001). Moreover, vitamin A and D toxicoses have been reported as a result of misuse of liquid vitamin supplementation in macaws (Takeshita et al., 1986; Shoemaker et al., 1997), cockatoos (Shoemaker et al., 1997), cockatiels (Koutsos et al., 2001) and conures (Bourke, 1997). Attempts have been made to correct the nutritional imbalance of domestic seeds by coating them with supplement. In a study conducted on African grey parrots, birds were offered such a diet and they selected mostly a seed diet. This self-selected diet was shown to be deficient in twelve vitamins, minerals and amino acids (Ullrey et al., 1991). When looking at daily intake of dietary essential amino acids in African grey parrots, while fed either with a seed mixture diet or with extruded pellets *ad libitum*, the authors did not find that amino acids were deficient in seed-based parrot diets (Kalmar et al., 2012). Nevertheless, formulated diet is more advisable.

Vitamin D toxicity leads to widespread calcification of soft tissue. Toxic levels can be transferred maternally to the embryo, leading to abnormalities in chick development. Vitamin A toxicity may lead to iron storage disease in cockatiels and lorikeets (Koutsos, 2003; McDonald, 2003a), pancreatitis (Koutsos et al., 2003; McDonald, 2003a) and vocalization changes (Koutsos, 2002) in cockatiel. Alternatively, a supply of carotenoids, like carrot juice or spirulina, instead of vitamin A, can be provided (McDonald, 2004b). Dietary vitamin A requirements have been established to 4000 UI/kg for cockatiel (Harrison et al., 2006). Excesses of vitamin A may interfere with uptake of vitamin E, increasing embryonic liver concentration at the expense of vitamin E, thus compromising the antioxidant status of progeny. This may decrease fertility, hatchability and survivability of chicks (Koutsos and Klasing, 2005). On the contrary, high doses of vitamin E decrease absorption of vitamin A, D and K. McDonald (2003b) found that it was possible to improve the health and productivity of large psittacines feeding the birds with organic formulated diets low in vitamin A.

Carciofi et al. (2003) evaluate the food intake of six parrots of five different species when fed with a fruit- and seed-based diet. The authors observed a great variation between individuals in terms of selectivity of alimentary items but a general trend to prefer seed over other food items (such as papaya), leading the diets to be nutritionally heterogeneous and non-balanced. The average diet consumed presented a marginal level of protein, high energy, low calcium, phosphorus and manganese and inadequate calcium/phosphorus ratio. Another study shows that each conure subject consumed a diet with unique nutritional characteristics and that the evaluation of the mean composition of the diet eaten by all birds may result in an incorrect assumption of what occurs with each bird individually (Carciofi et al., 2006). When given the choice, long-billed corellas (*Cacatua tenuirostris*) preferred hulled seeds in relation to whole ones, decreasing the general activity linked to deshulling (Waples et al., 2000). The feeding behaviour of the grey parrots and yellow-shouldered amazons (*Amazona barbadensis*) approximately doubled protein content, led to a three- to four fold increase in fat content and halved carbohydrate content in relation to the offered seed mixture diets (Kalmar et al., 2008a). This corroborates with the assertion that, in captivity, given a varied feeding and the possibility of choosing, psittacines do not present the capacity of nutritionally balancing their food (Ullrey et al., 1991; Kollias, 1995), rendering nutrient ingestion conditioned to the particular taste of each bird towards the offered foods.

High fat diet with low polyunsaturated fatty acids predisposes birds to atherosclerosis (Bain, 2012). Birds fed with dietary omega-3 (fish oil) supplementation show lower cholesterol and triglycerides in relation to the group receiving flax oil (Heinze et al., 2012). This type of diet supplementation can decrease the risk of developing atherosclerosis. On the contrary, another type of fatty acid present in seed mixture, α-linolenic acid (ALA) is thought to be a risk factor for this pathology. As the blood concentration of ALA is linked to the (food) intake, thus this later has to be the lowest as possible (Bavelaar et al., 2005).

The composition of 30 commercially available parrot seed mixtures have been analysed and compared to dehulled seeds (as parrots remove this part) and several commercial diets. The results revealed that most parrot species are fed a diet rich in fat and energy, and that the energy density of most formulated, pelleted/extruded diets is far below the energy density of common seed mixtures (Werquin et al., 2005). This type of unbalanced diet increases the catabolism of amino acids and leads to an increase of ketone body formation in psittacine birds (Kalmar et al., 2010e) that could lead to metabolism modification such as acidosis.

Seed mixes diet and multisystemic abnormalities

Birds offered seeds alone tend to have a higher body condition score. Obesity has been defined as a body

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weight in excess of optimal body weight >20% (Harrison et al., 2006). The basal metabolic rate (BMR) of psittacine birds depends upon the thermal climate of the species origin (Koutsos et al., 2001). According to McNab and Salisbury studies (1995), species originating from tropical climates have a BMR (kJ/day) = $4.184 \times 73.6 \times (\text{body weight in kg})^{0.73}$, whereas species originating from temperate climate of New Zealand and Australia have a 21% higher basal metabolic rate (McNab and Salisbury, 1995). The regulation of food intake is not always perfect, and obesity can result when diets with high energy density are fed. For instance, budgerigars fed a 13 MJ/kg of metabolizable energy were able to maintain their body weight, whereas those fed a 14 MJ/kg became obese (Drepper et al., 1988). In sedentary pet birds, overweight may be associated with pododermatitis, higher oxidative damages while performing an escape flight (Larcombe et al., 2010). This condition may predispose a bird to congestive heart failure, atherosclerosis, fatty liver and kidney disease and diabetes, although this condition is rare in psittacids (Murphy, 1992; Desmarchelier and Langlois, 2008). Deficiency of cysteine and methionine also predisposes to fatty liver syndrome (Harrison et al., 2006). In a study, a seed-based diet with 12.8% protein that was low in lysine resulted in increased body fat. However, the same diet supplemented with lysine was adequate to maintain weight and body composition in budgerigars (Underwood et al., 1991). So amino acid deficiencies of seed mix diets could also be responsible for obesity.

A study was conducted in budgerigars to compare haematological and biochemical parameters of two groups of birds fed either on seed mixture diet or on commercially formulated diet during 1 year (Fischer et al., 2006). The authors did not notice any difference regarding the haematological parameters. The group fed the seed mixture had significantly higher concentrations of glucose, albumin, triglycerides and uric acid and higher activity of aspartate aminotransferase, but the values were within the published reference ranges for normal birds.

Vitamin A is critical for vision, cellular differentiation and immune function (Koutsos et al., 2001). Hypovitaminosis A typically leads to keratinization of squamous cells (Koutsos et al., 2001). This is correlated with hyperkeratosis on the footpad and the plantar surface of the toes, leading to pododermatitis. Keratinization of the excretory ducts of uropygial gland results in impaction of this gland and predisposes to abscess formation (Harrison et al., 2006). In parrots, focal metaplasia of the excretory duct of the glandular epithelium of the salivary gland was identified when liver vitamin A levels reached extremely low levels (<50 IU/g liver) (Dorrestein et al., 1987). Clinical signs involving integumentary system also manifest as overgrowth of the beak and the nails. Epithelial metaplasia may predispose to dermatological, respiratory and kidney diseases (Harrison et al., 2006).

Reproductive success also greatly depends on the nutritional status of breeders and chicks. Seeds decrease reproductive performance because they lack calcium, lysine, vitamin A and E. Vitamin A deficiencies are correlated with increased time between clutches, reduced hatchability, increased embryonic mortality, decrease survival time of progeny, decreased testes size, failure of spermatogenesis and a decline in sexual activity in males (Zhengwei et al., 2000). If a breeder is fed a nutrient-deficient diet, embryo development may be affected by early embryonic death or developed poor feathering, facial dermatitis and reduced body weight (Koutsos and Klasing, 2005).

Blood calcium levels in birds depend on dietary calcium and vitamin D3 levels (Stanford, 2006). Some species also rely on UV B, which enable the bird to convert vitamin D2 into vitamin D3 (Stanford, 2006). In an experiment, African grey parrots were divided into two groups receiving either a formulated nugget diet or a seed mix. Nugget diet produced a statistically significant increase in both the ionized calcium levels and the 25-hydroxycholecalciferol levels over the seed-fed group, even if both groups received the same amount of UVb (Stanford, 2003). Improved breeding performances were also observed in the nugget-fed group. Calcium deficiency may lead to egg binding in laying birds. Additionally, calcium-deficient parents may give birth to osteodystrophic juveniles (Harcourt-Brown, 2003; Stanford, 2006). Clinical evidence indicates that calcium (Ca) requirement for maintenance is probably above 0.05% (Wolf et al., 1998). Most seeds commonly fed captive parrots have <0.1% Ca, and grains such as millet and corn, are especially low with <0.03% Ca. In addition, seeds can contain high levels of phosphorus (P), which can bind the calcium in phytate complexes (Stanford, 2006). Seeds therefore do not meet calcium requirements of psittacids. Suboptimal Ca supply and Ca/P ratio when fed seed-based diets are a well-known cause of impaired skeletal mineralization and are consistent with clinical presentation in practice (Wolf et al., 1998). Calcium enters in muscle contraction and its mobilization is important for egg laying in female. Deficiency could lead to nutritional secondary hyperparathyroidism (Wallach and Flieg, 1967), rachitis or osteomalacia (Kalmar, 2011). The optimal range of Ca/P ratio is between 2:1 and 1.5:1 (Wolf, 2002). Hypovitaminosis

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A, D3 toxicity and excess of dietary calcium could lead to chronic kidney diseases (Bain, 2012). It seems that birds do not select food based on potentially limiting minerals including sodium and calcium but select high value nutrition food: seeds (Gilardi and Toft, 2012). It is possible to supplement the seed diet with oyster shells or cuttlefish bone to increase the quantity of calcium intake.

In the wild, some psittacine birds time their breeding to the seasonal availability of higher protein foods, indicating that amino acid nutrition is a major determinant of reproductive output (Wilson et al., 1998; Houston et al., 2007). In captivity, cockatiels increase egg lay after protein content of the diet increases (Koutsos et al., 2001). In general, avian species are unable to synthesize the essential amino acids leucine, threonine, lysine, tryptophane, phenylalanine, valine, methionine and isoleucine (Koutsos et al., 2001). A requirement for glycine has been observed for the budgerigar, suggesting that psittacine birds are unable to synthesize enough glycine to meet metabolic demands (Taylor et al., 1994). The lysine requirement of cockatiel chicks from hatching to weaning was found to be 0.8% of the dry portion of diet (Roudybush and Grau, 1985). This high requirement is not met by seeds alone. Chicks fed with a lower rate of lysine achieve slower growth (Roudybush and Grau, 1985). However, on the contrary to poultry, lysine deficiency did not result in a lack of melanin pigment in feather pigmentation of psittacine chicks (Roudybush and Grau, 1985). Amino acid deficiency is manifested in reduced growth rates (Klasing, 1998) and anorexia (Koutsos et al., 2001). Adult cockatiel fed 70% crude protein for 11 months were able to maintain general conditioning without post-mortem renal abnormality in an experimental study (Koutsos et al., 2001). So, the role of high levels of dietary protein in gout of psittacine birds is not supported by experimental evidence, at least in cockatiels. However, sudden changes from low- to high-protein diets should be gradual because sudden changes might lead to hyperammonemia, elevated uric acid production and potentially nephritis and gout, especially in young birds (Koutsos et al., 2001). At the opposite, the supplementary feeding influences also the reproduction. For instance, in kakapo, supplementary feeding (high energy diet) causes a male-biased offspring sex ratio (Clout et al., 2002).

Immunity is also influenced by the nutritional status of the bird. Both deficiency and excess of dietary vitamin A suppress immune function (Koutsos and Klasing, 2005). In cockatiels, vitamin A deficiency may be associated with diarrhoea and pneumonia by impairing intestinal IgA response (Koutsos et al., 2003).

Current recommendations

Recommendation for psittacins is to provide each bird with 20% fruits and vegetables and 80% pellets (Reid and Perlberg, 1998). Kalmar (2011) and Slooten (2012) provide recent recommendations (review and new data) regarding the different nutritional requirement (protein, energy, vitamins, fat, etc.) of psitaccids bird. Commercial diets are formulated for different physiologic status. (Harrison et al., 2006). Energy requirement (kJ/kg diet) increases for hatchlings, whose growth is rapid, and for females a few days prior to egg production until the clutch is laid (Klasing, 1998). Usually, two different diets can be offered to accommodate these changing needs: a grower-breeder diet and a maintenance diet (Koutsos et al., 2001). In eight psittacin species, a study demonstrated that fledging success was greater when a pelleted diet was fed in place of seeds (90% success vs. 66%) (Ullrey et al., 1991). Moult may not be associated with change in diet formulation because increase in food consumption to meet energy requirements results in sufficiently increased amino acid intake: the percentage increase in the energy expenditure associated with moult often exceeds the percentage increase in protein needed (Murphy, 1996).

The heating of nutrients enhances their digestibility, making them more appropriate for geriatric and juvenile patients. This also provides more energy and nutrients to birds suffering from maldigestion caused by proventricular dilatation disease or by pancreatitis (Clubb, 2009). Some diets are compounded of organic food but there is no proof that is. It has been shown that some birds choose conventional seeds when given the choice (in relation to organic food). This could be explained either because conventional seeds have a higher protein rate or because of the animals' previous feeding habits (McKenzie and Whittingham, 2010). Different kinds of cooking processes are also available: pelletizing and extrusion. In the extrusion process, raw materials are ground to smaller particle size. The dry mix is passed through a preconditioner, where other ingredients are added, steam is also injected to start the cooking process. The preconditioned mix is then passed through an extruder and then forced through a die where it is cut to the desired length. Use of the extrusion cooking process (approximately 140 °C; Frame, 1994) induces protein denaturation, leading to inactivation of enzymes, and destruction of naturally occurring toxins (Riaz, 2000).

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This high digestibility makes it advisable for birds suffering from diseases leading to maldigestion like proventricular dilatation disease. This process of extrusion creates starch gelatinization but also Maillard products and fat hydrogenation among other things. A recent study showed that lower degree of starch gelatinization in extruded diets enhance digestibility in pigeons (Abd El-Khalek et al., 2011). Maillard products reduce the availability of amino acids, and fat hydrogenation leads to high level of fatty acids, which could increase the risk of atherosclerosis. The process decreases the number of micro-organisms (Riaz, 2000). This improves the safety of the final product but also inactivates probiotics. In the pelletizing process, feed ingredients are hammered to reduce the particle size. Ingredients are then batched, combined and mixed thoroughly by a feed mixer. Feed is conditioned and thermal treated (low temperature) in the fitted conditioners of a pellet mill. The feed is then pushed through the holes and a pellet die and exit the pellet mill as pelleted feed. Finally pellets are cooled. This process enables to spare probiotics. Cooking (roasting, pelletizing or extrusion) is designed to stabilize oils. However, depending on the lipase concentration in some seeds, like brown rice and oats, rancidity can occur. These ingredients need to be roasted or partially cooked separately, then mixed to other ingredients prior to final processing (Harrison et al., 2006). Overcooking is also associated with degradation of some nutrients and conversion of *cis* to *trans* fatty acids (Harrison et al., 2006). Formulation of commercial diet should include enough antioxidants such as vitamin E, A, C and carotenoids. Antioxidants help to counter the detrimental effects of oxygen-free radicals implicated in the development of cancer, inflammatory conditions and heart disease (Harrison et al., 2006). Antioxidants could be advisable for weaker birds (Larcombe et al., 2010).

Studies with captive adult parrots (Psittaciformes) indicate that particle size and the degree of starch gelatinization are important parameters of the diet, relating directly to the health and function of the intestinal tract (Janssens et al., 2004; Kalmar et al., 2007). Three hand-rearing formulas with identical nutrient composition but different native starch content and particle size as a result of applied processing conditions were used in the study on the growth of parrot chicks of the genus Amazona (Reinold et al., 2012). The authors find that diets with more native starch (bigger particle sizes) tend to have a positive effect on intestinal health and function of Amazon parrot chicks.

Finally, packaging impacts the quality for a commercial diet (Brennan, 2006) as it has to prevent exposure to light and oxygen to slow down auto-oxidation of fatty acids and triglycerides. That is why cardboard and paper boxes are not adequate, but at the same time soft plastics may act as phytoestrogens (Harrison et al., 2006). Even with adequate products, all food should be smelt when first opened to check it is not rancid (Harrison et al., 2006). Following these precautions, commercial diets are recommended to keep a companion bird healthy. A main advantage of pelleted diets over seed-based diets includes prevention of selective feeding behaviour.

Ethological perspectives

Consequences of captivity on bird diet

Feeding behaviour of birds represents a way to estimate parrots' health and welfare. Owners and breeders can observe either on: (i) overconsumption due to pharmacological treatment, behavioural disorders or just inadequate diet; or on the contrary; (ii) anorexia that could appear when food is not adapted or fresh enough (for fruit and vegetables), the bird has health problems (such as cardiac disease) or receive a treatment (for a review, see Bain, 2012). Controlling the diet and increasing the general activity would reduce risk factors of health problems. The diet of parrots influences their life span: granivorous, big parrots with communal roasting and periodic resource shortages live longer. The caloric restriction linked with the activity and the spare resources increases the life span (Munshi-South and Wilkinson, 2006).

Captivity imposes constraints on the expression of the normal behavioural repertoire. We can observe abnormal behaviour traducing an attempt to cope with adverse environment such as lack of space or social instability (Broom, 1991; Danzer, 1991). In general, psittacids, as other prey animals, are neophobic (Wilson and Luescher, 2006), and they tend to avoid new food items. The likelihood of neophobia or reluctance to novel food items is influenced by the extent of environmental enrichment in early life (Fox and Millam, 2007). In the wild, individuals can eavesdrop conspecifics, but in captivity, owners have to play this role. Studies on language learning show that Model/Rival method can help in the learning process as birds tend to compete for reward (Pepperberg, 1999) but also mimic the 'model' behaviour (vocal responses). Secondly, birds are programmed for important energetic cost for their daily life while foraging, defending their territory, breeding or escaping predator attacks for instance. In the wild, birds spend 90% of their active daytime foraging and preening (self and allopreening) (Engebretson, 2006). As this natural foraging

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behaviour is time consuming, birds have to eat energetic food and tend to favour protein and fat. The same is observed in captivity but in this situation, energetic expenditures are very limited because pet birds tend to be sedentary leading to obesity. In captivity, humans control food availability, variety, quantity and quality. Other factors can also influence food intake mainly indirectly when the general activity is modified because of the temperature, light/dark cycle or sexual status (e.g. courtship behaviour; Schnegg et al., 2007). On the contrary, the diet itself could influence the behaviour. The nesting behaviour of kakas, similar to kakapos, is synchronized to the abundance of specific food items for instance (Wilson et al., 1998; Houston et al., 2007). Snyder et al. (1987) documented that Puerto Rican Amazon parrots (*Amazona vittata*) spend approximately 4–6 h per day foraging across sites that could be distant from several miles. It is presumed that other psittacine species spend similar amounts of time searching for and acquiring food as part of their daily behavioural repertoire. In contrast, companion birds (captive) such as orange-winged Amazons (*Amazona amazonica*), spend approximately 30–72 min per day eating a pelleted diet (Oviatt and Millam, 1997) without travelling, manipulating food items (podomandibulation) or attempting to balance their own diet (Meehan et al., 2003b). Furthermore, the reduction in or even omission of the appetitive phase (foraging period) reduces the diversity of the parrots' behavioural repertoire (Kalmar, 2011).

In the wild, parrots fed on a huge variety of food such as seeds, fruits, flowers, leaves, bark or insect larvae. The study of Gilardi and Toft (2012) on 17 different species (of eight genera) living in Peruvian amazon revealed that their diet is diverse even if the seeds represent 70% of the food intake. This flexibility enables the birds to reduce the competition between individuals and species and also to adapt to the seasonal variation and other factors that could impact on the foraging areas. The same flexibility and diversity in the diet and feeding behaviour has been observed in several different species in other countries and continents: see, for example Best, 1984 *(Strigops habroptilus)*; Galeti, 1993 (*Pionus maximiliani*); Garnett and Crowley, 1995 (*Psephotus dissimilis)*; Renton, 2001 (*Amazona finschi*); Symes and Perrin, 2003 (*Poicephalus fuscicollis suahelicus)*.

Even when bred in captivity, exotic parrots are not considered domesticated animals and, as such, they retain the inherent behavioural and physical needs of wild parrots (Davis, 1998; Graham, 1998). For instance, their natural behaviour facing an apparent danger will be to fly away but most of the time they cannot (lack of space, deflighting method), and we can observe a redirection of the arousal that leads to decreased anxiety due to the stress (Jenkins, 1999). Moreover, psychogenic disorders can appear because the behavioural repertoire cannot be displayed normally. Secondly, the bird is often housed alone and tends to suffer from boredom. It has been suggested that the denial of these activities (social interactions and foraging) can cause both physical (Graham, 1998) and behavioural abnormalities in captive parrots (van Hoek and ten Cate, 1998; Garner et al., 2003b; Meehan et al., 2003a,b, 2004). The size of the cage and the general activity represent the main (physical) constrains linked to the captivity and could lead to feather-damaging behaviour (Seibert, 2006; Van Zeeland et al., 2009). Oral stereotypy (e.g. feather picking, bar chewing) is related to lack of opportunity to perform foraging behaviour. Lack of social interaction with the same species appears to contribute to the development of both oral and locomotor stereotypy (Sargent and Keiper, 1967; Keiper, 1969; Meehan et al., 2003a,b, 2004). Garner et al. (2003b) showed that stereotypy in captive orange-winged Amazon parrots (*Amazona amazonica*) is correlated with poor performance on a cognitive task (the 'gambling task'). The extent to which animals are positively or negatively affected by their captive environments is likely to depend on their cognitive abilities as well (Held et al., 2001). Parrots have been shown to have high-level cognitive abilities (Pepperberg, 1999; Péron, 2012). These abilities may be an important factor on parrots' susceptibility to develop abnormal behaviour in captivity (Birchall, 1990). In captivity, feeding time is short thus boredom and 'redirected foraging' resulting from lack of foraging opportunities (e.g. Meehan et al., 2003a,b; Lumeij and Hommers, 2008) can be observed. Plucking Crimson-bellied Conures (*Pyrrhura perlata perlata*) spend more time preening and are less active, spending less time flying and vocalizing (van Hoeck and King, 1997). In the same study, the severity of feather damages was correlated with the time spent preening. It was also shown that adding fruit basket and willow branches of different sizes increases exploration such as flying, hopping and climbing, and also manipulation with both foot and beak that competes with other activities such as preening or vocalizations. The experimenter observed a stabilization of the picking problem following this environmental enrichment (van Hoeck and King, 1997). Thus, it seems that oral activity with edible food or material is the expression of a natural behaviour for birds.

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Consequences of inappropriate diet on bird cognition

We have seen in the first part that imbalanced diet could impact general health. Regarding ethological aspects, birds kept on inappropriate diet can also exhibit behavioural modifications such as voice change, aggressiveness or apathy, which can be observed by the owner. The diet can directly impact on sexual display. The beginning of reproductive season could be influenced by modification of food quantity and quality (Perrins, 1970).

In other avian species, carotenoid supply can modify sexually selected colour signals. However, psittacin birds use psittacofulvin pigments instead of carotenoid pigments in their plumage. Therefore, diet does not seem to influence their colour (Knott et al., 2010). Despite lack of effects of dietary carotenoids on normal feather coloration, chronic malnutrition can induce aberrant feather pigmentation (Koski, 2002). Moreover, a typical indication of malnutrition, or even a period of impaired health, includes the presence of stress marks–horizontal, linear defects across the vane–at the feathers (Harcourt-Brown, 2000). It has been demonstrated that carotenoid content of the diet has an impact on avian oil droplets, located in retinal cones (Knott et al., 2010). A change in avian oil droplets' composition was observed after 2 months on carotenoid-free diet (Knott et al., 2010). It is therefore likely that a diet lacking carotenoids can modify colour vision in birds, therefore impacting their behaviour.

van Hierden et al. (2005) also found that supplementation with serotonin precursor tryptophan might improve feather picking in some cases. However, previous experiments in which specific amino acid deficiencies have been induced have not indicated increased behavioural disorders such as feather picking (Klasing, 1998). Vitamin A can lead to epithelial squamous metaplasia and subsequent behavioural disorders such as feather picking. Other minerals such as selenium also play a role in skin quality. It has been shown that cockatiels fed 100 000 IU vitamin A/kg diet had increased numbers of vocalizations in relation to an adequate vitamin level of 2000 IU/kg (Koutsos, 2002). However, whether or not this indicates cognitive disorder remains to be determined.

Does obesity lead to cognitive impairment in birds? In mice, scientists have strong evidence that high fat diet impairs cognition (and increases brain inflammation) (Pistell et al., 2010). Triglycerides are a major cause of cognitive disturbances in diet-induced obesity (Farr et al., 2008). In humans too, obesity has adverse effects on cognitive performances (Elias et al., 2005). In psittacids, whether or not obesity impacts cognitive abilities remains to be determined. On the contrary, deficit in high-quality fatty acid could lead also to some cognitive impairment. For instance, kittiwakes chicks fed with lipid-poor fishes have lower performances in cognitive task (Kitaysky et al., 2006) when compared to other birds fed with lipid-rich fishes. Omega-3 fatty acids are known to have a positive impact on health and cognition. Docosahexaenoic acid (DHA) is a long-chain polyunsaturated fatty acid, within the omega-3 family, which has been demonstrated to play an essential role in brain development in several species. DHA also impacts cognitive function because of its involvement in synaptic plasticity, neurotransmission, neurogenesis and its protective properties against oxidative damage to brain lipids and membranes that could cause loss of cognitive or motor skills (for review see Callicrate et al., 2011). A recent study conducted on budgerigars suggests that Docosahexaenoic acid (DHA) dietary supplementation (Callicrate et al., 2011) do not impact on birds' behaviour even if the authors do not know whether the quantity or the absorption were correct.

Food quality but also food distribution can predispose to behavioural disorders. Studies by Harcourt-Brown (2004) suggested that premature physical activity in hand-reared chicks may exacerbate the effects of a deficient diet and contribute to skeletal deformity. Furthermore, hand-rearing has the potential to produce physical as well as behavioural problems in parrots (Harcourt-Brown, 2004). In another study, lead on passerines, canaries that were forced to work for food compared to those which had free access to food also showed a reduction in stereotypic behaviour such as spot-picking (Keiper, 1969).

Furthermore, environmental enrichment can lead to better performances in cognitive tasks as it has been observed with chickens: the enrich group (with the opportunity to explore an outdoor free-range 1 week prior to the experiment) learnt the task faster(Krause et al., 2006). Tested with a Y-maze task, the enriched group left the start-box faster and was better in learning the task and made fewer initial mistakes. Garner et al. (2003a) already revealed that stereotyping birds display had poor results on a cognitive task. Nevertheless, to our knowledge, no study addressed the question of potential benefits of enriched environment on cognitive performances.

The diet as a way to enrich birds' housing conditions

Following the last paragraphs, it seems logical to assess that improving diet can be a way to prevent some

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behavioural disorders. In feeding trials with amazons, grey parrots and cockatoos, Wolf et al. (2002) noticed that the feeding pattern but not time spent for feed intake differed between pelleted/extruded diets and seed mixtures. A typical rhythm of feed intake was observed while offering seed mixtures *ad libitum* (higher ingesting activities in the early morning and in the afternoon), whereas formulated diets were ingested continuously during the whole day. Comparing the food intake and the budget time of rose-ringed parakeets (*Psittacula krameri*) feeding on either a extruded pellet diet or sunflower seeds *ad libitum*, the authors did not observe overfeeding in the pellet diet group even if their food intake was higher (Kalmar et al., 2010a). The same had been observed with grey parrots while fed either on a seed diet or on a pellet diet: their daily water and food intake was increased in the second situation (Kalmar et al., 2010d). Nevertheless, the voluntary energy intake was lower for the pellet diet group because of the energetic density of the food (compared to sunflower seeds) (Kalmar et al., 2010a). This indicates that the use of balanced foods, pelleted or extruded, tested with success by authors such as Roudybush et al. (1984) and Ullrey et al. (1991), is an important path to be considered in improving the nutrition of parrots in captivity. Dehusking seeds leads to an important increase in fat and protein content on account of a decline in crude fibre content (Kalmar et al., 2008b). Kalmar et al. (2010c) observed that providing apple to the amazons significantly lowered voluntary energy intake in birds by approximately 1/8.

Providing food items of different sizes and when possible in a very raw and natural form, such as non-peeled pellets, increases beak and tongue manipulation and oral activity, foot handling is thought to improve bird coordination and helps to maintain body condition. In a study, over-sized pellets (20–30 times larger) were preferred in captive orange-winged parrots (*Amazona amazonica*) compared to regular size because it increased the oral activity and provided enrichment foraging (Rozek et al., 2010). Moreover, birds were motivated to work in order to reach larger-sized pellet manipulating weighted-lid feeders even when regular pellets were freely available (Rozek and Millam, 2011). Then it seems that captive parrots display contrafreeloading–animals will work for a reward, in the presence of the same reward available freely (Elson and Marples, 2001; Van Zeeland et al., 2010).

Food provisioning should be realized at all times and not only when the owner is present. Owners have to make their bird as independent as possible, as it will feel less bored when left alone. Of course, part of the diet could be distributed when the owner is present to maintain the relation, and this moment can also be associated to medical training or behavioural modification sessions as a reward. Hand-reared birds are sensitive to food quantities and develop expectation when they see humans manipulating food. They are sensitive to their owner intention, such as teasing for instance (Péron et al., 2010) and can be aggressive when they feel frustrated, so owners should only use favourite food to work with their bird and should never starve it.

It has been demonstrated that it is possible to prevent and reduce behavioural disorders such as feather picking or stereotypies using physical and foraging enrichments (Meehan et al., 2003b). The general idea is to add elements in the environment so that a bird has to chew through barriers, manipulate objects through holes, sort through inedible material or open containers to obtain food items. In this study, the authors observed that foraging enrichment is more used compared with physical enrichment, which means that podomandibulation activity seemed to be compulsory. Thus, simply using a pipe feeder rather than a bowl to distribute the diet increases foraging time and improve feather picking score (Lumeij and Hommers, 2008) because the new activities enter in competition in the time budget.

Foraging material can be used to increase activity. Owners should try to dispense food, for example using shavings of wood. Food items should be placed in different areas,which are difficult to access like hung up toys that the bird could try to manipulate and destroy. Thus, enrichment programs create a competition in motivation, time budget and physical activities so that animals tend to be in better mental health as they can express their natural behaviour (Meehan et al., 2003b). Thus, the diet represents a way to increase environmental enrichment as several modalities are involved in foraging such as tactile, visual, olfactory and gustatory senses. In budgerigars (*Melopsittacus undulatus*), placing the feeder as far as possible under perch level increases bird activity: budgerigars come and feed more often but spend less time on the feeder because a lower position makes them more exposed to potential predators (Schnegg et al., 2007). Parrots feel sensory pleasure with food and are able to express it (Cabanac, 2009) or to ask for specific food (Pepperberg, 1998; Péron, in press). This ability could then take part in the foraging decision (favouring fat) but can be used also in the enrichment programme as a way to motivate the bird. Furthermore, offering of fruit next to a seed-based diet effectively reduces

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voluntary energy intake and can hence be applied to abate obesity (Kalmar et al., 2010c).

Parrots in captivity spend significantly less time in feeding and foraging activity and more in resting and maintenance behaviours than parrots in the wild. Food-based enrichment devices can be used to increase the levels of activity of captive parrots: increasing foraging and locomotor activities and on the contrary decreasing resting periods–that could lead to boredom–and maintenance behaviours–that could lead to feather-damaging behaviour–(Van Zeeland et al., 2009). Species-specific enrichments, designed to bring out wild-type behaviour, have a greater attraction for parrots than devices, which are less species specific (Elson and Marples, 2001).

Conclusion

To conclude, if owners want to improve the relation with their 'feathered apes' they should take care of their diet. Food quality and normal behavioural repertoire expression help the bird to be in good mental and physical health. Because parrots tend to select the food they preferred (over the food that could be the healthiest) and also because they dehull the seeds, we observed most of the time that their diet is unbalanced. Formulated diet seemed to be one of the best ways to feed these birds. Increasing the foraging time is also a good way to control the activity of the bird and to prevent some physiological and behavioural disorders. Even though the number of publications on psittacids nutritional requirement has increased over the last few years the data come from very few different species. In the future, it could be interesting to determine whether diet can improve cognitive processes in birds such as solving tasks and learning tricks.

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