A Review of Current Literature on Nutrition of Cage and Aviary Birds

Sandy Hume*

Introduction

In the last 10 years specific research and continuing avicultural interest have provided useful theoretical and practical information about cage and aviary birds, and yet there is still much to know about their specific nutritional requirements. Nutritional deficiencies are a major factor in many diseases, making correct nutrition imperative in any treatment or preventive medicine program.

This review concentrates on specific work relevant to cage and aviary species and considers current practices in Australia and other countries.

Current Knowledge

This is based on work in four main areas;

1) Poultry research
2) Observation of feeding activity in the wild
3) Observation by aviculturists
4) Specific research into cage and aviary bird nutrition

1. POULTRY RESEARCH

Research on the nutritional requirements of poultry has previously and currently provided most of the information about cage and aviary bird nutrition and diet formulation. A complete review of the nutrient requirements of poultry is regularly published by the American National Research Council (NRC).[24]

The increasing amount of nutritional research in non-poultry species (psittacine, passerine, raptorial and ratite birds, etc.) has shown that extrapolation from poultry studies can range from very useful to disastrously irrelevant. Some important differences between poultry and cage and aviary species are:

a) The young of psittacine, passerine and raptorial birds are altricial and often have changing and highly specialised requirements that must be supplied by their parents.
b) Different species grow at different rates [3,4,27] so the nutrient density fed to the parents must be adequate. Canaries reach 90% of adult body weight by 11 days[4], budgerigars in 25 days[2], cockatoos in 45 days[31], and meat chickens in about 55 days.[32]
c) Smaller species usually have higher metabolic rates and need more nutrients per unit of body mass.[27]

* **Highbury Veterinary Clinic, 128 Highbury Road, Burwood, Victoria, 3125**

d) The body composition of different species varies thus varying the nutrient requirements.[3,11]

e) Birds have evolved in different environments varying their ability to absorb, store and/or synthesise different nutrients. Specific environmental adaptations may also affect certain species' ability to digest or even find palatable important components of diets offered in captivity. For example many passerine birds are readily maintained on seed or seed-based diets but larger psittacine birds such as Amazons and *Eclectus* appear to require supplemental vitamin A if fed a seed-based diet.

2. FORMULATING NUTRIENT REQUIREMENTS FROM OBSERVATION STUDIES OF WILD BIRDS.

Relatively few of these arduous studies have been undertaken. Species documented include Eastern and Pale-headed Rosellas[33], Western Rosellas, Port Lincoln parrots, and Red-capped parrots[34], Budgerigars[35], White-tailed Black Cockatoos[36] and the Bahama Parrot[37]. A continuing study of 7 species of Macaw by Charles Munn of the New York Zoological Society is described in the New Scientist[38] but the article is unreferenced.

Two things emerge from these studies. Firstly all the observed species consumed a huge variety of plants including seeds, fruits, flowers and bark. In the Rosellas and Black Cockatoos, insects and their larvae are a staple at certain times of the year. Secondly, analysis of the plant species consumed shows that the seeds commonly sold as feed for captive species are rarely, if ever, consumed as part of the "natural" diet.

These studies are used to direct research into the nutrient requirements through nutrient analysis.[2,4,10,11] By comparing captive and wild bird diets areas of excess and deficiency have been identified but it is impossible to obtain specific, accurate figures on energy or nutrient requirements. In other words we know what they are eating but not how much or why.

3. FORMULATING NUTRIENT REQUIREMENTS FROM THE OBSERVATIONS OF AVICULTURISTS.

There are as many successful diets as there are successful aviculturists. Most of these diets are logical and effective and present a valid option for anyone wanting to keep healthy birds. The major drawbacks are that they are highly species-specific, complex and time consuming to prepare, and difficult to assess without a clinical trial that would be problematic for many bird owners and veterinarians.

4. SPECIFIC RESEARCH INTO CAGE AND AVIARY BIRD NUTRITION.

Nutritional research concentrates on three main areas:

a) Energy requirements
b) Major nutrient requirements (protein, fat, carbohydrates)
c) Minor nutrient requirements (vitamins, minerals, trace elements)

a. ENERGY REQUIREMENTS OF CAGE AND AVIARY BIRDS[1,2,3,4,5,10,11,14,15,17,19,20,27]

As with most other species birds eat primarily to satisfy energy requirements. Protein requirement is the next limiting factor dictating nutrient intake. For a diet to be "balanced" the individual nutrients must be adequate for health and in the correct proportion in relation to the energy density. If the energy density is too high the birds may eat less causing a deficiency in one or more nutrients. This is one of the major problems with seed-based diets. Conversely if energy density is too low nutrient excess can occur.

Therefore when formulating or assessing a diet two things must be known;

1) The energy density, or more correctly, the available energy of the diet; and
2) The energy requirements of the target species.

1) CALCULATING THE AVAILABLE DIETARY ENERGY.

The fate of dietary energy is usually shown as:

GROSS ENERGY (GE)	- faecal energy
DIGESTIBLE ENERGY (DE)	- urinary energy
METABOLISABLE ENERGY (ME)	- heat increment
NET ENERGY (NE)	- used for maintenance, production or stored.

As birds excrete both faeces and urine together their energy losses are pooled (excretory energy)[5] to allow estimation of ME. ME is used as the base measure of available energy in preference to NE which is closer to the true value of available dietary energy. This is due to the great variation of NE found within a species let alone between species and other technical difficulties making NE less predictive than ME.

Explanatory Note

ME is often used in two ways; firstly to describe the amount of energy available in a diet (dietary ME) and secondly as the ME required by a bird for maintenance, growth or reproduction (ME requirement).

Dietary Metabolisable Energy

Calculating dietary ME has been attempted extensively in poultry and less so in cage birds but still poses some problems as several variables will alter the available ME of a single diet.

a) Age: Juvenile birds and neonates often digest some nutrients less efficiently than adult birds, lowering the ME of the diet.[1,7]

b) Species: Smaller species may digest food more efficiently. Budgies and finches have been shown to convert 90% of GE to ME[4] whereas the domestic fowl can convert 75%[12] and the ostrich 65%.[1] On the other hand fibre digestion in adult ostriches is 60%[1,] in adult emus 40%[18], in adult chickens 6%[12] and in adult parrots is negligible presumably since they lack caecae.[19]

c) Nutrient balance: It was found in budgies, canaries and finches that as carbohydrate levels increase markedly, dietary ME falls.[4] In budgies it was shown that as protein levels increased dietary ME declined.[11]

This means that establishing the ME of a diet in one species does not necessarily make it applicable to other species. To this point dietary ME's have been researched extensively in poultry [12] and a few cage bird species including budgies[2,4,11], finches[4,19], canaries[4], rainbow lorikeets[15], ostriches[1], and emus.[18]

Methods of Establishing Dietary Metabolisable Energy.

Two basic methods are used:

1) Direct
2) Indirect

1. DIRECT METHODS

These are balance trials where the GE of a diet is established, usually by calorimetry. The faeces and urine are collected and their energy measured, leaving the remainder as ME. Whilst these methods are regarded as relatively accurate they are expensive, time consuming, must be repeated for every different diet, the methodology is varied and results are still prone to inconsistencies.[23,24]

2. INDIRECT METHODS

Two main types are used:

a) Biological assays which measure growth rate and/or body composition in relation to diet (these seem to have problems with inconsistency); and

b) Chemical assays where the protein, fat and carbohydrate content of the diet are measured and fed into a standard equation to give a predicted ME. This method is popular in the poultry feed industry as it is quick and cheap. Unfortunately the equation relies on the use of standard co-efficients for protein, fat and carbohydrates that leads to several problems. No adjustment for age is made yet younger birds digest fats less efficiently[24] and the different types of fats and proteins have different digestibilities. It has been found in poultry that there can be poor correlation between ME's established in balance trials and predictive equations.[12]

The Waltham Centre for Pet Nutrition[19] found that a poultry equation proposed by the NRC[13] in 1984 did not reflect directly measured ME's in budgies. The European community has continued to use a single predictive equation despite these difficulties[24,24]. In contrast the USA has attempted to counter the drawbacks of a single equation by establishing the ME of every single constituent of poultry feeds, e.g. sorghum, meat meal, milk powder, etc[12]. The results are added to give a cumulative ME. This huge task has improved the predictability of dietary ME's for poultry but it does not follow that these ME equations will be relevant to cage birds.

Summary

Knowing the ME of a diet is vital when calculating how much must be fed. Just as important is the method of calculation used as this dictates the accuracy and/or relevancy of the ME. As a rule the smaller the species the higher the ME. The smaller cage species have ME's that are up to 90% of GE compared to domestic fowl with an ME of 75% of GE. However reliable estimates of ME for diets fed to caged birds will only be available when relevant studies have been completed for each species.

2. Calculating the Energy Requirements of Cage and Aviary Birds

Establishing the energy requirements of captive bird species is more difficult than calculating the ME of a diet. Energy requirements are defined according to a scale of increasing energy expenditure.

a) Basal Metabolic Rate or Basal Energy Expenditure (BMR/BEE). BMR is measured when fasting, at complete rest, just after waking. It is most useful in people but usually regarded as impractical in animals due to the requirement for complete inactivity.[4] However a large amount of work has been done on establishing the BMR of birds either directly or indirectly (from REE or MEE).

b) Resting Energy Expenditure (REE).[4] This is sometimes used in place of BMR and includes the energy used for digestion.

c) Maintenance Energy Expenditure (MEE).[4] Probably the most realistic direct measurement as it includes REE and a minimum amount of physical activity. MEE has also been called existence energy, being the energy required to keep body weight constant in a thermoneutral environment and minimal activity levels.[5,15]

Methods of Measuring Energy Requirements

A. Direct Methods

1. Energy Balance

Using the same method as for calculating the ME of diet with the birds kept in a thermoneutral environment, minimal activity and maintaining constant weight.

MEE = ME(diet) = GE(diet) - Excretory Energy

2. Direct Calorimetry[23]

Heat production is measured by placing the bird inside a calorimeter and measuring basal metabolic heat emission and how heat production changes with diet and activity. Whilst accurate and repeatable the method is slow and expensive.

3. Indirect Calorimetry[23,26]

The principles and problems are the same but O_2 consumption and CO_2 production are measured.

4. Double Labelled Water[4]

Water is labelled with stable isotopes and CO_2 output is measured. This is sophisticated and expensive but is becoming increasingly used as it relatively accurate.

B. Indirect Methods

1. Predictive Equations

Predictive equations have been developed to calculate energy requirements at various levels of energy use. The perceived advantage is that direct experiments on a few species might provide the basis for calculating the energy requirements of many others. To date only a small number of cage bird species have been the subject of direct experiments and so predictive equations are commonly used. It will be shown below that when direct experiments are performed, predictions can differ markedly from experimental results.

The most important factor affecting metabolic rate is body size. As birds become larger their surface area : volume ratio decreases and so heat loss is reduced.

This relationship means that energy requirements and body size are not related by a linear, but an allometric relationship.

The most common form of predictive allometric equation is derived from experimental data subjected to regression analysis and generally expressed as;

Metabolic Rate or Energy Requirement (kj[or kcal]/day) = $K.W.^x$

K = a species specific constant that varies with activity levels
W = weight in kg
X = allometric exponent derived from the slope of a regression line derived from the results of direct energy requirement experiments.

DERIVATION OF THE ALLOMETRIC EXPONENT "X"

In the 1930's much work was done into how metabolic rate scaled with body size. The debate is continuing. Klieber[20] derived the allometric exponent 0.75 from work in mammals. This is often referred to as "Kleiber's rule" and is still widely used. More recent work[20,26] involving mammals, birds and reptiles has indicated that the allometric exponent 0.67 better reflects the relationship between metabolic rate and body surface area.

Bennett and Harvey[20] reviewed data from 399 bird species and used two definitions of metabolic rate:

1) Resting Metabolic Rate (RMR): Measured in inactive, unfed birds in thermoneutral conditions; and
2) Active Metabolic Rate (AMR): Less clearly defined as many methods were used. Most of the methods were indirect with derivation from allometric equations generated from small samples and simple multiples of RMR being the most common.

With respect to RMR Bennett and Harvey[20] found that no particular exponent was correct but that 0.67 conformed with the surface area to volume interpretation of metabolic scaling based on consideration of heat loss. A range of exponents was noted from 0.64 to 0.75. The allometric exponent for AMR was found to be ~ 0.61 and the slope of the regression line was not parallel to that of RMR. This indicated that smaller species use more energy when active than larger species and the common practice of calculating AMR as a multiple of RMR is invalid as the ratio between the two is not constant.

DERIVATION OF THE ALLOMETRIC CONSTANT "K"

This is the most variable part of the allometric equation:

$ME = K.\ W.^X$

The allometric constants are derived from the same regression equations as the allometric exponents. They are highly variable and this variability seems directly related to the allometric exponent. They do not seem directly comparable unless the same allometric exponent has been used. As expected the values for "K" increase in the smaller more metabolically active species. A set of K values has been proposed for five broad taxa:[39]

Taxon	"K" Value (kcal)	"K" value (kj)	Allometric exponent
Passerine birds	129	541	0.75
Non-passerine birds	78	328	0.75
Placental mammals	70	294	0.75
Non-placental mammals	49	206	0.75
Reptiles	10	42	0.75

NOTE: This set of "K" values is expressed as kilocalories (kcal). Other K values may be expressed as Kilojoules (kj). 1 kcal = 4.2 kj

Further "K" and "X" Values from the Literature

Taxon/Species	"K" Value(kj)	Allometric Exponent	Reference
Finches	535 (fasted)	0.715	19
Finches	669 (unfasted)	0.715	4
Budgerigars	740	0.75	19
Budgerigars	104.3	-0.96	2
Canaries	840	0.75	3
Passerines	481	0.62	27*
Passerines	531	0.724	5*
Passerines	540	0.724	5*
Non-passerines	322	0.723	5*
Non-passerines	328	0.792	5*
Non-passerines	414	0.62	27*
Free Living Birds	854	0.61	27*
Free Living Birds	920	0.61	27*
All captive birds	350	0.67	4*

*Denotes allometric equations cited from these references.

Discussion

The literature reviewed provided many examples of allometric equations for calculating the energy requirements of resting and active birds. Unfortunately most of them are descriptive, i.e. related to a specific experiment, e.g. ME = 104.3 $W^{-0.96}$ (reference 19) rather than predictive and more widely applicable. A general predictive equation was proposed by **Lasiewsky and Dawson** that would apply to all birds from hummingbirds to ostriches[4];

ME (kj/day) = $350W^{0.67}$

However Nott and Taylor[4] found that the predicted requirements were 30% lower than their experimental results with small passerines. When this equation was applied to psittacine species, finches and canaries with energy requirements derived from experimentation (see tables below), it was found to generate a result an average of 50% lower than the experimental values.

Nott and Taylor[19] put forward an alternative equation for calculating the energy requirements of companion birds:

ME (kj/day) = $740W^{0.75}$

The results derived from this equation were an average of 15% lower than the experimental values shown in the tables below. In contrast my analysis found the results from the literature more closely reflected by the equation:

ME (kj/day) = $740W^{0.67}$

Whilst all-encompassing predictive equations are desirable and useful, it seems that for captive birds they must be derived from proper, controlled experiments performed on the relevant species in order to be valid and accurate. At this stage no general predictive equation fulfils these criteria.

However, there is increasing activity in this area and below is a summary of published experimental work on the energy requirements of pet birds. Included in the table is a comparison with the three previously mentioned general predictive allometric equations for calculating the ME of cage and aviary birds.

M.E. Requirements of Budgerigars

Reference	**Experimental ME (kj/35gm bird/day)**	**Comparison with predicted ME's (kj/35gm bird/day)**		
2	62	$350W^{0.67}$ 37	$740W^{0.67}$ 78.3	$740^{0.75}$ 59.9
4*	77			
4*	73			
20	81			
11	83			
(Average ME)	75			

NOTE: 1) all results calculated for 35gm adult bird.
2) * indicates results cited from this reference

M.E. Requirements of Finches

Species	Weight	Experimental ME(kj/bird/day)	Predicted ME(kj/bird/day) for same average weight		
			$350W^{0.67}$	$740W^{0.67}$	$740W^{0.75}$
**E. troglodytes*	6.8gm	25.4	12.4	26	18
**U. bengalus*	8.7gm	26	14.6	30.8	21
**Lonchura spp*.	11.5gm	31.6	17.6	37.1	26
**P. guttata*	11.7gm	39.5	17.8	37.6	26.3
Finch spp(4)	10gm	25	16.9	33.8	23.4
Finch spp.(27)	10gm	28	16.9	33.8	23.4
Average ME(kj/bird/day)		29.3	16.1	33.2	23.0

NOTE: 1) * indicates results derived from Bennet and Harvey,(1987)[20]
2) (4) indicates results cited by Nott and Taylor.[4]
3) (27) indicates results derived from Kirkwood.[27]
4) ME is taken as 2x BMR or 2x RMR
5) ME = kj/bird/day

M.E. Requirements of Canaries

Reference	Experimental ME	Comparison with Predicted ME for 22gm Bird		
29	44.5	$350W^{0.67}$	$740W^{0.67}$	$740W^{0.75}$
19	57.5	27.1	57.4	42.3
20	65.5			
Average	58.5			

NOTE: 1) All birds weighed an average of 22gm
2) ME = kj/bird/day

ME Requirements for Other Psittacine Birds

Referenc e	Species	Weight	Experimental ME	Comparison with Predicted ME		
				$350W^{0.67}$	$740W^{0.67}$	$740W^{0.75}$
15	*T. haemotodus* (Rainbow lorikeet)	150gm	202	98.2	207.6	178.4
20	*Agapornis* spp	48gm	80.6	45.8	96.8	75.9
20	*Neophema* spp	97gm	97.0	40.5	85.6	66.2
20	*Myopsitta* spp	80gm	110.4	64.4	136	111
20	*Loriculus* spp	27gm	90.0	31.2	65.8	49.3
20	*Bolborynchus* spp	56gm	105	50.6	106.9	84.8
20	*Amazona* spp	338gm	369	169	358	328

NOTE: 1) ME = kj/bird/day

ENERGY REQUIREMENTS DURING REPRODUCTION

In a study of budgerigars[2] it was found that a 50 gm bird

1) prior to breeding consumed an average of 85 kj/bird;
2) during mating and incubation consumed an average of 110 kj/bird; and
3) when feeding 3 chicks a pair ofadult birds consumed an average of 240 kj/bird.

Energy Requirements During Growth

Budgerigars[2] and Canaries[3] have been studied during growth but direct estimations of their energy requirements are not known. It should be noted that the growth rates of these and other small species of bird are phenomenal, with canaries reaching more than 75% of adult body weight by 11 days and budgerigars by 21 days.

Conclusion

It can be seen that although the research on the energy requirements of caged and aviary birds has increased significantly, it is far from comprehensive and results and methodology are inconsistent. The search for a predictive allometric equation is not complete, despite good evidence for allometric relationships among avian families.[20]

It may be noted that none of the manufacturers of commercial complete diets for cage and aviary species (with the possible exception of Wambaroo products) supply or publish any data on the ME content of their diets with respect to the target species.

Roudybush et al[22] have produced a substantial body of work relating mainly to the specific nutrient requirements of the cockatiel. However no work has been published by this group relating to the ME of diet or the ME requirements of cockatiels. Roudybush et al[22] state the ME values for Roudybush diets designed for granivores (the vast majority of cage and aviary species) are derived from poultry data. They make the point that where specific information about energy requirements are unavailable the most reliable approach is to make a best guess followed by close monitoring of the clinical response, primarily measurement of daily body weight.

In respect of future developments in the area of energy requirements, American workers are concentrating on the individual nutrients and virtually ignoring energy requirements. European workers are doing a lot of work on both energy and nutrient requirements. The Waltham group (UK) seem likely to introduce a 'complete' diet in the near future.

Protein Requirements of Cage and Aviary Birds

After energy, protein is the most important component of the diet. Birds eat to satisfy both energy and protein needs. If either are not in the correct proportions excesses or deficiencies of these and other nutrients are likely. Protein must be both in the correct proportion and also contain the right amounts of essential amino acids. Birds contain up to 30% of body protein in their feathers causing a large sulphur amino acid requirement during growth and moulting.[5]

Seed-based diets can result in lysine and methionine deficiencies in adult birds whilst growing birds may have the additional complications of glycine and proline deficiency.[5,19]

Avian Amino Acid Requirements

Essential Amino Acids	Non Essential Amino Acids
Lysine	Alanine
Arginine	Aspartate
Histidine	Glutamate
Leucine	Glycine
Isoleucine	Serine
Threonine	Proline
Tryptophan	Cystine
Methionine	Tyrosine

Phenylalanine

Valine

(Glycine and Proline in young birds)

PROTEIN REQUIREMENTS OF COCKATIELS

Adult Maintenance

Roudybush[16] reports that adult cockatiels may be maintained on as little as 4% protein if the amino acids are balanced. Dietary protein of 10-15% seems ideal and was found to be clinically effective allowing for such contingencies as moulting or illness.[16]

Growth

The protein requirements of growing cockatiels are reported to be 20%[7]. It was found that as protein fell below this level, reduced growth and increased mortality occurred. At 25% protein and above behaviour abnormalities and reduced growth occurred.[7]

Roudybush[7] also determined that the requirement for lysine is 0.8% of the diet and noted that choline deficiency (requirement unstated) caused achromatosis of the wing and tail feathers.

Breeding

As for all altricial species breeding adults must be provided with a diet that will ensure the nestlings obtain their requirements, i.e. 20% protein for cockatiels.[7]

Protein Requirements of Budgerigars

Adult Maintenance

Earle and Clarke[2] report that the maintenance protein requirement for the adult budgerigar is 10%. In contrast Underwood et al[11] found that 12% protein was too low and 27% too high, and that the maintenance protein requirement was best met in birds fed diets containing 17-22% protein.

Growth and Breeding

Nott and Taylor[19] stated that analysis of crop fluid produced by adult birds showed a protein content of 24-26%. They claimed that chick development was better when birds were fed diets of at least 25% protein. However no controlled experimental evidence of this was offered.

Nott and Taylor[8] also found that by increasing the glycine content of the diet from 0.27% contained in a standard seed mix (Trill®) to 1.5-3% there was increased growth in budgerigar nestlings in the first 10 days post-hatch. This had no effect on later stages of growth.

Protein Requirements of Canaries

Adult Maintenance

Research with passerine birds (sparrows) has indicated that 8-9% protein was sufficient for adult maintenance.[19]

Growth and Breeding

Kamphues and Meyer[3] found that protein levels of 16.5-22% were adequate for growing canaries.[3]

Protein Requirements of Pigeons

Adult Maintenance

Dietary protein of 13% has been found adequate.[19]

Growth and Breeding

A dietary protein of 18% has been shown to be effective.[19]

Protein Requirements of Large Psittacine Birds and Finches

So far these requirements have not been determined but estimates of 10-20% have been recommended for both groups of birds for maintenance, growth and breeding. These estimates appear to be based on clinical response and extrapolation from other species.

PROTEIN AND GOUT

Ullrey et al[10] in their review of psittacine nutrition, found no evidence that excess protein (up to 80% of diet) caused gout in captive bird species. Work with normal domestic fowl indicated that unless there was a genetic susceptibility, an underlying disease process such as vitamin A deficiency or renal infection or high levels of gizzerosine (a by-product of cooked fishmeal), then gout could not be induced in experimental birds.

FAT REQUIREMENTS OF CAPTIVE BIRDS

The two main functions of dietary fat are to provide energy and fat soluble vitamins. High fat diets result in obesity, as birds eat to excess to meet other nutritional requirements.[19]. For maintenance dietary fat levels of 5-10% should be adequate. It should be remembered that seed-based diets can contain up to 50% fat. Higher levels of fat may be required during growth, moult and egg laying. In poultry linoleic acid has been found to be the essential fatty acid as it will eliminate the signs of fatty acid deficiency. The daily requirement for linoleic acid in poultry is 1%.[19]

CARBOHYDRATE REQUIREMENTS OF CAPTIVE BIRDS

Birds can be categorised into two broad groups based on the utilisation of carbohydrate or protein as their primary energy source.[5]

1) carbohydrate-based diet; 55% CHO, 20% protein, 15% fat
   frugivores, nectivores, granivores.
2) protein-based diet; 50% protein, 20% fat, 15% CHO
   raptors, piscivores, carnivores

It seems unlikely that a carbohydrate deficiency could occur with any currently used diet. Excess carbohydrate intake is possible, however excessive fat intake is more likely.

OTHER NUTRIENTS WITH VALUES SPECIFICALLY MEASURED IN CAPTIVE BIRDS.

In this section only those nutrients with values derived specifically from work on cage birds will be covered in detail. Those nutrients not derived from specific work on cage and aviary birds will be indicated by; (poultry). The poultry values are taken from the NRC Nutrient Requirements of Poultry, 1994[19]. At this stage only a few vitamin, mineral and trace element requirements of cage and aviary birds are known.

MINERALS

Calcium and Phosphorus

Two main diseases are associated with calcium (Ca) and phosphorus (P) imbalances.

1) Nutritional secondary hyperparathyroidism, commonly seen in growing cage birds due to an incorrect Ca : P ratio. This is due to low dietary Ca and/or high dietary P. Despite great interest in this area little direct work has been done in caged and aviary birds with recommendations being mostly based on poultry requirements.

2) Rickets is due to vitamin D3 deficiency impairing absorption and metabolism of dietary calcium.

Maintenance Calcium Requirements (All Birds)

1) Recommended Ca : P ratio; 2:1[19]
2) Recommended dietary calcium; 0.35-1%[7,19]. 1% should be the dietary maximum as work in poultry has shown that levels greater than this can cause decreased growth, nephrosis and weight loss[12].

Calcium Requirements During Reproduction

Reference	Species	Ca % in Diet
10	Larger psittacines	1%
7	Cockatiels	0.35%
19	Budgerigars	0.8%

Recommended Ca : P ratio; 2:1 for all birds

Calcium Requirements During Growth

Reference	Species	Ca % in Diet
19	Budgerigars	0.8% (19)

Recommended Ca : P ratio 2:1 for all birds during growth.

NOTE: It should be remembered that calcium is marginal or deficient and often poorly balanced in all the commonly used seed mixes.[10] Complicating this is the formation of unabsorbable calcium soaps by the oils in the seeds, rsulting in faecal calcium loss. In summary it seems that a Ca : P ratio of 2:1 and available calcium of 0.8% of the diet would satisfy the requirements of most aviary species for maintenance, growth and reproduction.

Magnesium

Deficiency is uncommon but may be associated with chronic gastroenteritis or protein deficiency. Requirement; (poultry).

Potassium

Deficiency is commonly characterised by neuromuscular dysfunction of skeletal, smooth and cardiac muscle. Water loss and diabetes are the most common causes of deficiency. The requirement is 0.20-0.25% of diet (poultry).

Sodium and Chloride

These two ions are mainly involved in acid base regulation and water balance. The optimum ratio in the diet is 1:1 (poultry).

TRACE ELEMENTS

Copper

Plays a major role in many enzyme systems especially those in red cells. The minimum requirement is 4-6 ppm (poultry).

Iodine

Deficiency is best documented in budgerigars manifested clinically by goitre and thyroxine deficiency. 2ug twice weekly was found to be prophylactic[19] otherwise no specific recommendations have been made for cage birds. The use of a supplemented diet such as Trill® may also be an effective preventive.
The requirement for poultry is 0.35mg/kg feed.

Iron

Iron is utilized mostly in heme compounds and mitochondrial energy systems. Iron deficiency is thought to be common in birds[31]. Recommendations are 0.01% of diet[80mg/kg of feed] (poultry).

Manganese

Has many important functions involving muscle, tendon, bone and clotting factors. There is a recommendation of 25mg/kg feed (poultry).

Selenium

It appears to be closely related to many but not all of the antioxidative functions of vitamin E. Both deficiencies and toxicities have been reported in poultry and cage and aviary birds. The dietary recommendation is 0.06mg/kg feed (poultry).

Zinc

Excess causing toxicity is commonly reported (often in conjunction with lead) but deficiency has not been reported in cage birds.

VITAMINS

Vitamin A

African Greys, Amazons, Eclectus, Gang-Gangs and Budgerigars are the species most commonly reported with vitamin A deficiency[2,5,19]. Whilst requirements are not known several recommendations have been made based on clinical experience[cited from 5].

Species	Vitamin A requirement
Budgerigars	50-100 iu/day
Cockatoos	200 iu/day
Macaws	500 iu/day

The most common cause of vitamin A deficiencies are seed-based diets as they provide little or no vitamin A or β-carotene (vitamin A precursor). Green and yellow vegetables contain a lot of -carotene and cod-liver oil and egg yolk are good sources of vitamin A. However vitamin A is toxic and excessive supplementation with cod-liver oil is a common problem.[19]

Vitamin D

High levels are found in most seeds so problems mainly occur in birds with little exposure to sunlight. The only published requirements are for poultry:[12]

Poultry 50-100 iu/day

Hypervitaminosis D has been reported mainly in hand-reared, over supplemented birds, especially Macaws.[5,6] Vitamin D is reported to have a wide safety margin and the toxic level in poultry is $1x10^6$ iu/kg of feed[12].

Cod-liver oil is often used as source of vitamins A, D and E however it contains high levels of gizzerosine predisposing birds to gastric ulcers.[5] Also the high levels of unsaturated fatty acids present in cod liver oil are thought to deplete the vitamin E through oxidation.

Vitamin E / Selenium

Harrison and Harrison[30] reported that cockatiels with a leg paralysis syndrome responded to supplementation with vitamin E/selenium. The author has seen a similar problem in a lutino Cockatiel being parent raised on a seed based diet. Both wings and legs appeared paretic. The owner reported that this had occured previously involving four birds from the same parents. These birds recovered in a few weeks after being placed on a commercial hand rearing mix until weaning. The bird presented made a clinical recovery in 3-4 days after being supplemented with vitamin E (Micelle E) 40 i.u., b.i.d. and Calcium Sandoz syrup 1ml b.i.d. Notably this bird and one of the previous birds were left with a slight leg lameness which may indicate thepresence of a pathological fracture and a primary calcium deficiency.

Wilson[46] found that wild lorikeets in Queensland with leg and wing paralysis due to a myopathy responded to vitamin E. The addition of selenium gave no improvement and predisposed the birds to injection abscesses. Interestingly this syndrome seems to differ histologically and possibly aetiologically from a clinically similar disease seen in lorikeets from the Sydney area. It should be noted that seeds usually have adequate levels of vitamin E.

B - Complex Vitamins

Knowledge of requirements and imbalance syndromes are currently derived from research in poultry.

VITAMIN	REQUIREMENT/mg/kg bird/day
B 1/Thiamine	0.04
B 2/Riboflavin	0.2
Niacin	0.6
B 6/Pyridoxine	0.2
Pantothenic acid	0.4
Folic acid	0.02
Biotin	0.005
B 12/ Cyanocobalmin	.0004

Vitamin C

With the exception of the red vented Bul-Bul and a species of sun bird, birds are not thought to have a dietary vitamin C requirement.

Vitamin K

Vitamin K is synthesized by bacteria in the lower intestine in birds. It is thought that overuse of antibiotics or vitamin A may compromise this. No recommendations have been made for cage and aviary birds. Requirements; (poultry) 0.05mg/kgbird/day.

A Comparison of Diets Commonly Fed to Cage and Aviary Birds

There are three basic dietary options:

1) Seed-based; often 100% seed offered and the bird selects only one type.
2) Prepared diets. Favoured by many aviculturists they are prepared to a personal recipe developed through experience.
3) Commercial complete diets. These are generally pelleted diets designed to provide a balanced diet if fed solus.

SEED-BASED DIETS

Seed-based diets are not balanced. They tend to have excess fat, often greater than 50%, and this, coupled with low protein content (11%), tends to result in obesity as birds eat to fulfil both energy and protein needs.[11] Seeds are often deficient in Ca, P, Na, Mn, Zn, Fe, I, Se, vitamins A, D ,E, K, B_{12}, choline, riboflavin, pantothenic acid and niacin.[9,10,11]

Budgerigars, finches and cockatiels seem to tolerate diets of 50-80% seeds, if provided with some form of supplementation. However obesity, fatty livers, and diabetes mellitus especially in budgerigars, are very common with seed-based diets.

The larger parrots are also very prone to problems on seed-based diets as their diets in the wild contain few, if any, seeds. Obesity, vitamin A deficiency, fatty tumours, atherosclerosis, fatty livers, diabetes mellitus and pancreatic necrosis have been reported especially as some birds become fixated on a single seed type.[42,43,44,45]

Certain types of seed such as white millet, canary seed and oats are relatively low in fat and can be useful, especially in weight reduction programs.

PREPARED DIETS

These diets are generally very effective as experienced aviculturists are usually well informed about the nutrient requirements of the species they keep through observation and personal research. Aside from poorly formulated diets their major disadvantage is they are highly variable and often complex and time consuming to produce. This tends to make them less attractive to the casual aviculturist or the pet bird owner.

They are greatly encouraged and widely used in the USA as the veterinary profession and aviculturists make a concerted effort to keep pet birds off seed-based diets. Whilst this can mean considerable effort for both veterinarian and bird owner it has proven successful in improving the nutrition and health of pet birds.

COMMERCIAL COMPLETE DIETS

Nutritionally complete commercial diets have become widely available in the last decade with the bulk of them originating in the USA. The extruded diets offer several advantages.The cooking process destroys many pathogenic organisms, increases the digestibility of some nutrients and allows the formulation of nutritionally consistent, specialised diets for all parts of the bird life cycle.[10,11] Perhaps the most attractive feature is their convenience for the consumer as most are recommended to be fed solus.

Work by Ullrey et al[10] showed that their formulated pelleted diet was well accepted and improved fledgling percentages when compared to seed mixes. The extrusion made up 80% of the diet on a dry basis with the rest being fruit and vegetables. Interestingly it was found that if seeds were added to this mixture they were eaten in preference to the extrusion, lessening its effectiveness.
Several disadvantages of the complete diets exist. Parrots habituated to seed are resistant to change and great efforts must be made to introduce these diets.

Parrots especially can find these diets uninteresting as visual cues are important in feeding behaviour. In an analysis of 11 commercial diets advertised as nutritionally complete and available in the USA, Ullrey et al[10] reported a significant number of nutrient deficiencies and excesses involving protein, Ca, P, Na, Zn and Mn. The diets were not mentioned by name in this study.

Several diets are available in Australia. As the Australian labelling laws do not require a typical analysis to be displayed on the packaging only a brief synopsis(usually called a "Guaranteed Analysis") tends to be shown. Approaching the manufacturers directly although helpful did not produce a complete nutrient analysis. A useful table is published in Burgmans' book; Feeding Your Pet Bird[30] giving a typical analysis of 8 common maintenance diets. Appendix 1 shows an analysis of the major nutrients of some of the commercial complete diets available in Australia performed by Dr. J. Mercer from the Faculty of Veterinary Science at the University of Sydney.

CONCLUSION

There is little doubt that seed only diets are nutritionally substandard. Even if they are supplemented with fresh food or extruded diets there is every chance that the bird will selectively eat the seed.

The prepared diets can be completely balanced, very palatable and are highly recommended with inconvenience being their major drawback.

The commercial complete diets are an excellent alternative to seed-based diets but it must be remembered that while they claim to be nutritionally complete the nutritional requirements of cage and aviary birds are not fully known. These diets should be used with caution especially when they are first introduced with close observation to ensure that birds are eating the diet and not losing condition. In addition careful record keeping particularly of reproductive and fledging performance should be maintaned in the longer term.

Future developments should bring more specific information about the nutritional requirements of cage and aviary birds. Consequently the commercial diets should become more standardised and consistent.

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