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Formulated Diets Versus Seed Mixtures for Psittacines[1,2]

Nutrition of Caged Birds

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ABSTRACT **Psittacines are often classified as seed eaters despite studies that have established great diversity in food habits in the wild. While seeds are consumed, so are flowers, buds, leaves, fruits and cambium. Some psittacines consume parts of >80 species of grasses, forbs, shrubs and trees. In addition, insects may be important. Although there are few controlled studies of the requirements of psittacines, it is probable that most nutrient needs are comparable to those of domesticated precocial birds that have been thoroughly studied. Commercial seed mixes for psittacines commonly contain corn, sunflower, safflower, pumpkin and squash seeds, wheat, peanuts, millet, oat groats and buckwheat, although other seeds may be present. Because hulls/shells comprise 18% - 69% of these seeds and they are removed before swallowing, a significant proportion of typical seed mixtures is waste. Some of the seeds also are very high in fat and promote obesity. Common nutrient deficiencies of decorticated seeds include lysine, calcium, available phosphorus, sodium, manganese, zinc, iron, iodine, selenium, vitamins A, D, E and K, riboflavin, pantothenic acid, available niacin, vitamin B-12 and choline. Attempts to correct these deficiencies by incorporating pellets into seed mixes are usually thwarted by rejection of the pellets and disproportionate consumption of items that are more highly favored. An extruded diet formulated to meet the projected nutrient needs of psittacines was fed with fruits and vegetables to eight species of psittacines for 1 y. Fledging percentage was increased to 90% from the 66% observed during the previous 2 years when these psittacines were fed seeds, fruits and vegetables. Although this extruded diet was well accepted in a mixture of fruits and vegetables and met nutrient needs, analyses have shown that not all commercial formulated diets are of equal merit. J. Nutr. 121: S193-S205, 1991.**

Indexing Key Words

symposium · birds · psittacines · seed · composition · nutrient · requirements · formulated diet · gout

Aviculturists often classify caged birds on the basis of their apparent food preferences in captivity (1). The Psittacidae comprise a family of birds with stout, hooked bills commonly called seed eaters despite field studies (2-5) establishing great diversity in food habits in the wild. Psittacines are widespread in tropical and south temperate areas of the world, with major populations in the neotropics and Australia. These regions vary widely in rainfall and temperature and in the food plants that the environment will support (6). Since indigenous psittacines coevolved with their

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food supply, their food choices in an undegraded habitat represent a nutritional wisdom built on generations of experience. However, studies of caged psittacines suggest that the nutritional wisdom of wild birds does not transfer to captive birds offered cultivated seeds as their principal food. In fact, specific instances of failed dietary husbandry based on seed mixtures have led to this review of natural dietary habits of certain psittacines, the nutritional limitations of seeds and the development of diets formulated to be nutritionally complete.

Food Selection By Certain Wild Psittacines

Biologists with significant field experience will testify how difficult it is to gather quantitative food intake data on free-living birds. Even qualitative information is difficult to gather. Nevertheless, the following reports illustrate the diversity of food choices in the wild and the opportunity such diversity provides for meeting nutrient needs.

Cannon (4), in a study of the diets of Eastern (*Platycercus eximius*) and Pale-headed (*P. adscitus*) Rosellas in Queensland, Australia, spent over 200 h in each of two study areas observing food consumption by these two species throughout the year. Both study areas had been modified from their primitive state by agricultural practices, including cultivation of alfalfa (*Medicago sativa*), milo or grain sorghum (*Sorghum bicolor*) and oats (*Avena sativa*). Some regions were pastured, and seeds in dung were consumed. Food plants used by Eastern and Pale-headed Rosellas included grasses, forbs, shrubs and trees, and these psittacines fed on 82 and 47 plant species, respectively. Both rosellas fed mainly on fruits and seeds and to a lesser extent on flowers. In addition, significant intakes of insects were noted, particularly during July when coccids and psyllids attached to Eucalyptus leaves constituted nearly 50% of the diet of the Eastern Rosella.

Saunders (2) studied the food habits of the short-billed form of the White-tailed Black Cockatoo (*Calyptorhynchus funereus*) in two areas of Western Australia. The clearing of woodlands had degraded the habitat to some extent, and in one study area, parent birds were forced to forage over long distances to find adequate food for their nestlings. Because this effort was only partly successful, growth rates of the young, fledging weights and breeding success were lower than in the area where large amounts of native vegetation were available close to nest sites. A total of 30 plant species was exploited in the two nesting areas, with flowers and seeds being the main parts eaten. Some plant species were parasitized by insects whose larvae developed in the flowers or stems. Larvae from the families Cerambycidae and Pyralidae were identified in the crops of nestlings in sufficient numbers to suggest deliberate collection. The nonbreeding season was characterized by some change in food plants, partly as a consequence of seasonal environmental change and partly due to migration to areas of improved food availability. The two populations of cockatoos fed on a total of over 30 species of plants during the nonbreeding season. The seeds of pine species were particularly important to one population. Insect larvae were also consumed.

Wyndham (3) studied the food habits of the budgerigar (*Melopsittacus undulatus*) in inland mideastem Australia. This region is characterized by open or lightly timbered plains and a few remnant mountain ranges. It is semiarid to arid, east to west, and rain falls primarily in the summer in the north and in the winter in the south. Seeds from 21 to 39 species of ground plants were eaten depending upon area. No plant food from upper vegetational strata and no insects were identified in crop contents. The seeds eaten had a mean length from 0.5 (*Eragrostis spp.*) to 2.5 mm (*Astrebla squarrosa*). Most seeds were intermediate in this range and weighed (with husk) from 0.36 to 1.33 mg. The seeds were normally husked before being swallowed. Diet choices appeared to be governed largely by availability.

Snyder et al. (5), in a broad study of the biology of the Bahama Parrot (*Amazona leucocephala bahamensis*), presented some observations on its food habits. This species was first cited as endangered in 1966 (7). A small population lives on the low limestone island of Abaco, the second largest of the Bahamian Islands. A second population lives on the island of Great Inagua. Abaco's climate is subtropical with an average rainfall of 154 cm. Monthly temperature means range from 21° to 27°C. The geology of Great Inagna is similar to that of Abaco, but it is much drier, with a mean annual rainfall of 70 cm. Monthly mean temperatures range from 24° to 29°C. Bahama Parrots were observed feeding on 16 plant species. They were catholic in their tastes and ate the inner portions of green, unopened Pinus caribaea cones, stems of woe vine (*Cassytha filiformis*), fruits of wild dilly (*Manilkara bahamensis*), cinnecord (*Acacia choriophylla*), poisonwood (*Metopium toxiferum*) and naked wood (*Myrcianthes fragrans*), and the fruit and inner bark (*cambium*) of Caribbean pine. They also fed on the fruit or seeds of wild tamarind (*Lysiloma latisiliquum*), jumbay (*Leucaena leucocephala*), sea grape (*Coccoloba uvifera*), buttonwood (*Conocarpus erectus*), buffalo top palm (*Thrinax morrisii*), silver top palm (*Coccothrinax argentata*), Tabebuia bahamensis, Bursera simaruba, Swietenia mahagoni and Sabal palmetto.

It is apparent that, except for millet (*Panicum milioides*), which may be eaten by wild budgerigars in agricultural areas, most seeds found in mixtures sold for caged psittacines are foreign to the experience of their free-living relatives. Since this is true, it is appropriate to compare the nutrient composition of these cultured seeds with the nutrient requirements of the birds to which they are fed. By this means one can identify potential deficiency problems and develop a strategy to correct them.

Nutrient Requirements

Most of the information we have on quantitative nutrient requirements of birds has been obtained from studies of precocial species. Much of this information has been summarized in the National Academy of Sciences/National Research Council (NRC) publication on Nutrient Requirements of Poultry (8). Nutrient requirements presented in this document are defined as established values, based on research data, or estimated values, where experimental evidence is less than complete. The NRC nutrient requirements for growth of seven precocial species have been recalculated and presented in **Table 1**. The recalculation was made to convert the NRC requirements, expressed in diets as fed, to a dry matter basis. This was done by dividing the NRC values by 0.9, assuming that feedstuffs used in poultry diets contain an average of 90% dry matter. Similar recalculations were made for NRC nutrient requirements for breeding birds, and these recalculated values are presented in **Table 2**. Only those nutrients that are expected to be of practical importance in diets containing natural feedstuffs are listed.

It should be noted that the NRC nutrient requirements do not include a margin of safety to account for variations in nutrient concentration or availability in feed ingredients or for nutrient losses during diet processing and storage.

Table 1

Nutrient requirements for growth of precocial birds[1]

Nutrient	Chickens[2]	Turkeys	Geese	Ducks	Pheasants	Bobwhite Quail	Japanese Quail
			g/kg dry matter				
Protein	260	310	240	240	330	310	270
Arginine	16.0	17.8	–	12.2	–	–	13.9
Isoleucine	8.9	12.2	–	–	–	–	10.9
Lysine	13.3	17.8	10.0	12.2	16.7	–	14.4
Methionine	5.6	5.9	–	–	–	–	5.6
Methionine + Cystine	10.3	11.7	8.3	8.9	12.2	–	8.3
Threonine	8.9	11.1	–	–	–	–	13.3
Tryptophan	2.6	2.9	–	–	–	–	2.4
Linoleic Acid	11.1	11.1	–	–	11.1	11.1	11.1
Calcium	11.1	13.3	8.9	7.2	11.1	7.2	8.9
Phosphorus, avail.[3]	5.0	6.7	4.4	4.4	6.1	6.1	5.0
Potassium	4.4	7.8	–	–	–	–	4.4
Sodium	1.7	1.9	–	1.7	1.7	1.7	1.7
Chlorine	1.7	1.7	–	1.3	1.2	1.2	2.2
Magnesium	0.7	0.7	–	0.6	–	–	0.3
			mg/kg dry matter				
Manganese	67	67	–	44	–	–	100
Zinc	44	83	–	67	–	–	28
Iron	89	89	–	–	–	–	111
Copper	9	9	–	–	–	–	7
Iodine	0.39	0.44	–	–	0.33	0.33	0.33
Selenium	0.17	0.22	–	0.16	–	–	0.22
Vitamin K	0.56	1.11	–	0.44	–	–	1.11
Riboflavin	4.00	4.00	4.44	4.44	3.89	4.22	4.44
Pantothenic Acid	11.10	12.22	16.67	12.22	11.11	14.44	11.11
Niacin	30.00	77.78	61.11	61.11	66.67	33.33	44.44
Vitamin B12	0.01	0.003	–	–			0.003
Choline	1444	2111	–	–	1667	1667	2222
Biotin	0.17	0.22	–	–	–	–	0.33
Folacin	0.61	1.11	–	–	–	–	1.11
Thiamin	2.00	2.22	–	–	–	–	2.22
Pyridoxine	3.33	5.00	–	2.89	–	–	3.33
			IU/kg dry matter				
Vitamin A	1667	4444	1667	4444	–	–	5555
Cholecalciferol	222	1000	222	244	–	–	1333
Vitamin E	11	13	–	–	–	–	13

[1] Recalculated from Nutrient Requirements of Poultry (8) and expressed on a dietary dry matter basis. Values derived from requirements for the following periods after hatching: chickens, 0-3 wk; turkeys, 0-4 wk; geese, 0-6 wk; ducks, 0-2 wk; pheasants, starting; bobwhite quail, starting; Japanese quail, starting and growing. ME concentrations (J/kg dry matter) of diets to which these requirements apply are chickens, 14.88; turkeys, 13.02; geese, 13.48, ducks, 13.48; pheasants, 13.02; bobwhite quail 13.02; Japanese quail, 13.95.

[2] Meat type.

[3] Commercial feed ingredients of plant origin have 60 to 70% of their phosphorus bound in phytin. Utilization of phytin phosphorus by young or adult poultry is considered negligible.

Table 2

Nutrient requirements for breeding of precocial birds[1]

Nutrient	Chickens[2]	Turkeys	Geese	Ducks	Pheasants	Bobwhite Quail	Japanese Quail
g/kg dry matter							
Protein	160	160	170	170	200	270	220
Arginine	8.2	6.7	–	–	–	–	14.0
Isoleucine	6.3	5.6	–	–	–	–	10.0
Lysine	5.7	6.7	6.7	7.8	–	–	12.8
Methionine	3.9	2.2	–	–	–	–	5.0
Methionine + Cystine	6.1	4.4	–	6.1	6.7	–	8.4
Threonine	5.3	5.0	–	–	–	–	8.2
Tryptophan	1.4	1.4	–	–	–	–	2.1
Linoleic Acid	–	11.1	–	–	11.1	11.1	11.1
Calcium	30.6	25.0	25.0	30.6	27.8	25.6	27.8
Phosphorus, avail.[3]	2.8	3.9	3.3	3.9	4.4	5.6	6.1
Potassium	(1.7)	6.7	–	–	–	–	4.4
Sodium	1.1	1.7	–	1.7	1.7	1.7	1.7
Chlorine	(1.7)	1.3	–	1.3	1.2	1.2	1.7
Magnesium	(0.6)	0.7	–	0.6	–	–	0.6
mg/kg dry matter							
Manganese	(67)	67	–	28	–	–	78
Zinc	(72)	72	–	67	–	–	56
Iron	(67)	67	–	–	–	–	67
Copper	(9)	9	–	–	–	–	7
Iodine	(0.33)	0.44	–	–	0.33	0.33	0.33
Selenium	(0.11)	0.22	–	0.16	–	–	0.22
Vitamin K	(0.56)	1.11	–	0.44	–	–	1.11
Riboflavin	(4.22)	4.44	4.44	4.44	–	4.44	4.44
Pantothenic Acid	(11.11)	17.78		11.11	–	16.67	16.67
Niacin	(11.11)	33.33	22.22	44.44	–	22.22	22.22
Vitamin B12	(0.004)	0.003	–	–	–	–	0.003
Choline	–	1111	–	–	–	1111	1667
Biotin	(0.17)	0.17	–	–	–	–	0.17
Folacin	(0.39)	1.11	–	–	–	–	1.11
Thiamin	(0.89)	2.22	–	–	–	–	2.22
Pyridoxine	(5.00)	4.44	–	3.33	–	–	3.33
IU/kg dry matter							
Vitamin A	(4444)	4444	4444	4444	–	–	5555
Cholecalciferol	(556)	1000	22	556	–	–	1333
Vitamin E	(11)	28	–	–	–	–	28

[1] Recalculated from nutrient Requirements of Poultry (8) and expressed on a dietary dry matter basis. ME concentrations (J/kg DM) of diets to which these requirements apply are chickens, 13.25; turkeys, 13.48; geese, 13.48; ducks, 13.48; pheasants, 13.25; bobwhite quail, 13.25; Japanese quail, 13.95.

[2] Meat type, except values in parentheses are for Leghorn type.

[3] Commercial feed ingredients of plant origin have 60 to 70% of their phosphorus bound in phytin. Utilization of phytin phosphorus by young or adult poultry is considered negligible.

Controlled research on nutrient requirements of altricial birds is very limited. Roudybush and Grau (9) studied the protein requirement of hand-fed cockatiel (*Nymphicus hollandicus*) chicks, using purified diets containing various proportions of isolated soybean protein and crystalline DLmethionine. When the effects of diets containing 5, 10, 15, 18, 20, 25 or 35% protein upon weight gain and mortality were examined from 4 to 28 d after hatching, these workers concluded that 20% protein was the lowest concentration permitting maximal growth. When Grau and Roudybush (10) fed a purified diet supplying amino acids in crystalline form (20% protein equivalent) and studied the effects of lysine concentrations of 0.2, 0.4, 0.6, 0.8 and 1.2% upon weight gain and mortality in cockatiels from 4 to 28 d after hatching, they concluded that 0.8% lysine was the minimum requirement. It may be significant that body weights of cockatiel chicks at 14 and 28 d were about twice as great when chicks were fed a control diet containing 20% protein from isolated soybean protein as compared with chicks fed the crystalline amino acid diet with 0.80% lysine.

While these data are inadequate from which to generalize, they provide no clear evidence that dietary protein and lysine requirements of growing psittacines deviate appreciably from the needs of growing precocial birds about which we know so much. Based on data on cockatiels (9), seven species of macaws, nine species of cockatoos, two species of parrots and six species of amazons (11), psittacine chicks that are hand-fed appropriate diets will gain weight even faster than meat-type chickens for several weeks after hatching. To support these rapid rates of gain and normal body composition, it seems reasonable that the nutrient densities of diets fed to growing psittacines should be at least as great as those found necessary for slower growing precocial birds.

Nutrient Composition of Seeds

Commercial seed mixtures for psittacines commonly contain corn, sunflower, safflower, pumpkin and squash seeds, wheat, peanuts, millet, oat groats and buckwheat. Other seeds that may be present include milo, rice, niger, hemp, canary grass, rape, flax, sesame, anise, fennel, lettuce, false flax, poppy, pea, caraway and teazle. Some psittacines are also fed Brazilnuts, English walnuts, cashew nuts, hazelnuts, almonds, macadamia nuts, pistachio nuts, beechnuts, pinyon nuts and pecans. The common and scientific names of these seeds are presented in **Table 3**. The proportions of seeds in five commercial products sold in the United States are shown in **Table 4**.

Those seeds that have a separable hull/shell are decorticated (husked) by many psittacines before swallowing. Proportions of hull/shell and kernel that have been determined gravimetrically are presented in **Table 5**. Because hulls/shells comprise 18 to 69% of these seeds, a very significant proportion of typical seed mixtures offered to psittacines is waste. In addition, as can be seen in **Table 6**, nutrient analyses of whole seeds can present a distorted view of the nutrients provided by the seed after the hull/shell has been removed. The impact of decortication by psittacines upon nutrients actually entering the digestive compartments of the gastrointestinal system has been determined for products P and T in **Table 4**. Analyses of product P for protein (dry basis) as sold and after decortication give concentrations of 14 and 18%, respectively. Like analyses of product T give respective protein concentrations of 17 and 23%. These comparisons assume that the ingredients will be consumed in the proportions in which they are presented. This is unlikely, however, since most birds favor certain items and partly or totally reject others. Thus, nutrient intakes from self-selected diets based on mixtures of seeds are highly unpredictable.

Table 3

Common and scientific names of seeds to psittacines

Common Name	Scientific Name
Almonds	*Prunus dulcis*
Anise seed	*Pimpinella anisum*
Beechnuts	*Fagus spp.*
Brazilnuts	*Betholletia excelsa*
Buckwheat	*Fagopyrum esculentum*
Canary grass seed	*Phalaris canariensis*
Caraway seed	*Carum carvi*
Cashew nuts	*Anacardium occidentale*
Corn	*Zea mays*
English walnuts	*Juglans regia*
False flax seed	*Camelina sativa*
Fennel seed	*Foeniculum vulgare*
Flax seed	*Linum usilatissimum*
Hazelnuts	*Corylus spp.*
Hemp seed	*Cannabis sativa*
Lettuce seed	*Lactuca sativa*
Macadamia nuts	*Macadamia spp.*
Millet, common or proso	*Panicum milioceum*
Millet, spray or foxtail	*Setaria italica*
Milo (grain sorghum)	*Sorghum bicolor*
Niger	*Guizotia abyssinica*
Oat groats	*Avena sativa*
Pea	*Pisum spp.*
Pecans	*Carya illinoensis*
Pinyon nuts	*Pinus edulis*
Pistachio nuts	*Pistacia vera*
Poppy seed	*Papaver somniferum*
Pumpkin seed	*Cucurbita spp.*
Rape seed	*Brassica rapa*
Rice	*Oryza sativa*
Safflower seed	*Carthamus tinctorius*
Sesame seed	*Sesamum indicum*
Squash seed	*Cucurbita spp.*
Sunflower seed	*Helianthus annuus*
Teazle seed	*Dipsacus spp.*
Wheat	*Triticum vulgare*

Table 4

Ingredients in seed mixes for psittacines[1]

Ingredients	Products sold in USA in 1990 (coded)				
	P	Q	R	S	T
			g/kg		
Buckwheat	–	–	29	37	63
Canary grass seed	–	–	–	170	–
Corn grain	335	128	51	–	70
Hemp seed	–	22	2	–	–
Millet seed, various types	–	–	219	322	62
Oat groats	–	106	112	37	62
Peanuts with shell	84	47	–	–	–
Peanuts without shell	–	–	15	–	254
Pellets	–	155	119	67	108
Pepper pods and seed	18	10	15	–	–
Pumpkin/squash seed	100	–	4	–	–
Rape seed	–	–	–	130	–
Safflower seed	142	261	226	146	242
Sunflower seed	290	248	55	–	–
Wheat	31	23	134	49	140
Miscellaneous	–	–	19	43	–

[1] Determined gravimetrically on physically separated samples with total wights of 80-1087 g in Comparative Nutrition Laboratory, Michigan State University, E. Lansing, MI.

Table 5

Proportions of hulls/shells and kernels in seeds

Seed	Hull/shell	Kernel
	g/kg	
Almonds[2]	600	400
Beechnuts[2]	390	610
Brazilnuts[2]	520	480
Buckwheat[2]	200	800
Canary grass seed[3]	180	820
English walnuts[2]	550	450
Hazelnuts[2]	540	460
Macadamia nuts[2]	690	310
Millet, common or proso[3]	260	740
Peanuts[2,4]	270	730
Pecans[2]	470	530
Pinyon nuts[2]	430	570
Pistachio nuts[2]	500	500
Pumpkin/squash[2,4]	260	740
Safflower seed[2]	490	510
Sunflower seed, confectionary type[2,4]	460	540

[2] From Composition of Foods: Nut and Seed Products (12).

[3] From McDaniel (13).

[4] Determined in Comparative Nutrition Laboratory, Dept. of Animal Science, Michigan State University, E. Lansing, MI.

Table 6

Effect of hulls on composition of seeds[1]

Seed	Dry matter	Crude protein[2]	Crude fat	Crude fiber	Ca	P	Mn
			g/kg dry matter				*mg/kg dry matter*
Pumpkin seed							
Without hull	949	302	477	30	0.9	13.7	31
Hull	923	159	36	659	1.5	1.3	137
Safflower seed							
Without hull	944	171	407	26	0.8	6.8	–
With Hull[3]	953	144	395	279	1.7	3.7	20
Sunflower seed							
Without hull	951	217	519	36	1.4	5.6	19
Hull	911	27	22	682	2.8	0.4	7

[1] Determined in Comparative Nutrition Laboratory, Dept. of Animal Science, Michigan State University, E. Lansing, MI.

[2] N x 5.30 (14).

[3] Analyses were not performed on safflower hull alone.

The nutritional weaknesses of seeds are apparent when the nutrient concentrations in **Table 7** are compared with the nutrient requirements of precocial birds in **Tables 1 and 2.**

Only three seeds (peanuts, pumpkin/squash and sunflower) appear to provide enough protein to meet the needs for growth. Of these, peanuts are deficient in sulfur amino acids (methionine plus cystine) and marginal in threonine when amino acid concentrations are expressed as a percent of protein concentration and are compared with like expressions of need. Peanuts, pumpkin/squash and sunflower seeds also are very high in fat and metabolizable energy (ME) (24.27-25.52 kJ/g of dry matter). Thus, protein and amino acid concentrations of these seeds, expressed per unit of ME, are lower than protein and amino acid requirements that are given by the NRC (8) for diets that typically supply 12.97-15.06 kJ ME/g of dry matter. In addition, the high fat level in these seeds leads to obesity, which is a significant problem in some psittacines (17).

Other nutrient deficiencies for growth in most of the seeds in **Table 7** include calcium, available phosphorus, sodium, manganese, zinc, iron, vitamins A, D and K, riboflavin, pantothenic acid, available niacin (18), vitamin B-12 and choline. With respect to seeds in which alpha-tocopherol concentrations have been determined, vitamin E activity may be marginal to deficient because other evidence (19) suggests that requirements for support of normal vitamin E stores in birds and prevention of hepatic microsomal peroxidation are greater than the requirements given by the NRC (8). In addition, the high concentrations of unsaturated fatty acids in peanuts, pumpkin/squash, safflower and sunflower seeds lead to increased vitamin E requirements (20). Iodine and selenium concentrations vary with the region in which the seeds are grown. Three samples of safflower seed (including hull) that were analyzed in the Michigan State University Comparative Nutrition Laboratory had selenium concentrations ranging from 0.11 to 1.76 mg/kg dry matter. Selenium concentrations in corn have been shown to range from 0.01 to 2.03 mg/kg (21).

Table 7

Composition of seeds fed to psittacines[1]

Nutrient	Corn[2]	Proso millet[3]	Oat groats[4]	Peanuts[5]	Pumpkin/ squash[5]	Safflower[5]	Sunflower[5]	Wheat[2]
				g/kg dry matter				
Dry matter	890	919	870	934	931	944	946	880
Crude protein	97	150	182	275	264	171	241	144
Crude fat	43	40	70	527	492	407	524	18
Crude fiber	26	185	30	52	24	26	44	28
Arginine	5.6	3.8	10.2	37.0	58.2	18.5	25.4	6.7
Isoleucine	4.2	5.4	5.9	10.7	18.2	7.6	12.0	6.7
Lysine	2.7	1.4	6.1	10.6	26.5	5.7	9.9	4.6
Methionine	2.2	1.0	2.4	2.8	7.9	2.7	5.2	2.2
Methionine + cystine	3.6	2.5	4.7	6.3	12.3	5.6	10.0	5.2
Threonine	4.4	3.8	5.1	8.0	13.0	5.5	9.8	4.3
Tryptophan	1.0	2.1[2]	2.2	3.3	6.2	1.7	3.7	2.1
Linoleic Acid	24.9	7.8[2]	–	166.3	204.3	297.5	344.9	6.8
Calcium	0.2	0.1	0.8	0.6	0.5	0.8	1.2	0.6
Phosphorus, total	3.1	4.0	4.8	4.1	12.6	6.8	7.5	4.3
Magnesium	1.3	1.8	1.3	1.9	5.7	1.7[6]	3.7	2.0
Potassium	3.4	4.8[2]	3.9	7.7	8.7	4.6[6]	7.3	5.2
				mg/kg dry matter				
Sodium	300	28[2]	575	17.1	22[6]	40[6]	32	460
Manganese	6	14[2]	32	12	31[6]	34[6]	21	37
Zinc	15	22[2]	–	35	88[6]	65[6]	53	36
Iron	30	82[2]	84	35	54[6]	89[6]	72	57
Copper	4	12[2]	7	11	19[6]	19[6]	19	1
Selenium	0.04	0.08[2]	–	0.34[6]	0.14[6]	0.84[6]	0.77[6]	0.23
Beta-carotene	1.4[6]	–	0	0	2.3	0	0.3	0
Alpha-tocopherol	9[7]	–	17	98	–	–	–	15
Riboflavin	1.1	4.2[2]	1.4	14.0	3.4	4.4	2.6	1.6
Pantothenic Acid	4.5	12.1[2]	15.7	30.0	–	–	–	11.4
Niacin	27.0	25.3[2]	11.5	151.5	18.7	24.2	47.7	55.2
Vitamin B-12	0	0[2]	0	0	0	0	0	0
Choline	697	484[2]	1300	–	–	–	–	1253
Biotin	0.07	–	–	–	–	–	–	0.13
Folacin	0.45	–	0.57	1.08	–	–	–	0.46
Thiamin	3.9	8.0[2]	7.5	7.1	2.3	12.3	24.3	5.2
Pyridoxine	7.9	–	1.1	3.2	–	–	–	3.9

[1] Hull/shell removed from proso millet, oats, peanuts, pumpkin/squash, safflower and sunflower (confectionary) before analysis except as indicated in following footnotes.

[2] Data derived from ref. 8 except as indicated. Hull present on millet.

[3] Data derived from ref. 13 except as indicated.

[4] Data derived from ref. 15.

[5] Data derived from ref. 12 except as indicated. This reference is a useful source of nutrient information on other seeds as well.

[6] Analyzed in Comparative Nutrition Laboratory, Dept. of Animal Science, Michigan State University, E. Lansing, MI. Hull present on safflower.

[7] Data derived from ref. 16.

The inadequacies of these seeds for growth apply generally for reproduction and, to a lesser extent, for maintenance of adults. While most nutrient requirements decline as a percentage of dietary dry matter for reproduction as compared with early growth, certain seeds are still deficient in essential amino acids, and most or all are marginal to deficient in calcium, available phosphorus, sodium, manganese, zinc, iron, iodine, selenium, vitamins A, D, E and K, riboflavin, pantothenic acid, available niacin, vitamin B-12 and choline. Calcium requirements for egg production by psittacines are not likely to be nearly as high as they are for domestic poultry. The latter species have been selected for high egg production, and Leghorn-type chickens regularly produce >=260 eggs per year. While psittacines may produce several clutches of eggs per year in captivity, and the mineral in egg shells is principally calcium carbonate; the extra demands of intermittent egg production appear to be met by calcium withdrawn from skeletal reserves as long as dietary calcium concentrations are sufficient to fill those reserves during nonlaying periods. The calcium concentrations of the seeds in **Table 7** are not adequate for this purpose, but field experience with formulated diets suggests that ~1% calcium in dietary dry matter is sufficient for reproduction in psittacines.

Assuming that a cultivated seed mixture could be assembled that would meet nutrient needs if completely consumed, it is difficult to prevent preferential self-selection of favored but nutritionally unbalanced foods. The radiograph shown in **Figure 1** was taken of a rachitic, 8-wk-old Timneh African Gray Parrot (*Psittacus erithacus timneh*) that was fed principally corn from a seed mix by its parents.

Figure 1 Radiograph of an 8-wk-old Timneh African Gray Parrot that was fed mainly corn from a seed mix by its parents. Note the rickets and folding fractures.

Formulated Diets

The use of seed mixtures as food for captive psittacines has a long-abandoned historical precedent in the poultry industry. When the nutrient requirements of domestic birds were identified, it was soon established that growth, reproduction and long-term health were much improved by feeding complete formulated diets. Thus, seed mixtures were replaced by mash, pellets or crumbles that met specific needs for energy, amino acids, essential fatty acids, minerals and vitamins. Hatchability, chick viability, normal feathering and resistance to disease increased dramatically.

Attempts have been made to correct the limitations of seeds by coating them with vitamin and mineral suspensions or solutions, or by including a pelleted supplement in the mix, as has been done in products Q, R, S and T in **Table 4**. Supplement coatings are largely lost when the hulls are removed as the seeds are eaten. Powdered supplements commonly separate from the food that is eaten and are not consumed. In addition, commercially available supplements are not generally interchangeable because they vary greatly in composition. Thus, if they were to be consumed, nutrient deficiencies might still be evident, or nutrient excesses or imbalances may result. Supplement pellets frequently are not eaten, and their effectiveness suffers from disproportionate consumption of items in the seed mix that are more favored but are poorer sources of nutrients.

The sensory systems used by birds in the selection of food have been studied only to a limited extent. Some birds respond to visual or olfactory cues. Some apparently can taste sugars in food or water. Many birds, including psittacines, also have a tactile bill-tip organ (**Fig 2**) that assists them in the identification, selection and manipulation of food (22). It is probable that size, shape and texture are important in the food choices that psittacines make.

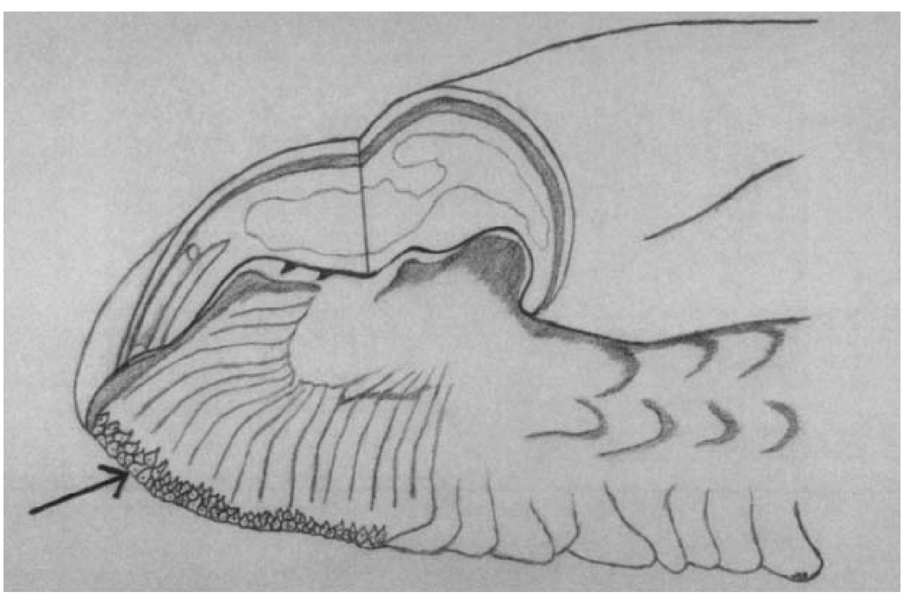

Figure 2 Schematic drawing of the bill tip organ in the upper beak of the goose. The arrow points to the conical tips of the touch papillae. These structures were first described in the lower mandible of the parakeet in 1869 by E. Goujon in the *Journal de l'Anatomie et de la Physiologie Normales et Pathologique de l'Homme et des Animaux*. Drawing adapted from ref. 22 by J. B. Bernard.

Table 8

Food selected by Timneh Gray Parrots from a mix of seeds, fruits, vegetables and an extrusion[1]

Food item	Dry matter in food item	Percent of diet consumed	
		Fresh basis	Dry basis
	g/100 g food	%	
Corn	89.0	33.8	42.4
Sunflower seeds	95.2	24.3	32.6
Peanuts	94.1	4.8	6.4
Safflower seeds	93.1	0.7	1.0
Extrusion	91.0	8.6	11.3
Oranges	14.0	6.0	1.2
Sweet potatoes	30.6	8.0	3.4
Celery	5.9	4.1	0.4
Green beans	9.9	5.4	0.8
Carrots	11.8	2.0	0.4
Spinach	9.3	2.8	0.4
Total		100.5	100.3

[1] Mean of 9 weekly values for 3 parrots.

Table 9

Food selected by 5 psittacine species from a mix of fruit, vegetables and an extrusion[2]

Food item	Dry matter in food items	Percent of diet consumed	
		Fresh basis	Dry basis
	g/100 g food	%	
Extrusion	91.0	41.8	81.1
Oranges	14.0	16.3	4.9
Sweet potatoes	30.6	12.7	8.4
Celery	5.9	11.1	1.4
Green beans	9.9	8.7	1.8
Carrots	11.8	7.6	1.8
Spinach	9.3	1.8	0.4
Total		100.0	99.8

[2] Mean of 7 daily values for 5 pairs of psittacines.

Table 10

Fledging percentage associated with feeding of seeds, fruit and vegetables or an extrusion, fruit and vegetables to 8 species of psittacines

Food item	Diet strategy	
	Seeds, fruit, veg[3]	Extrusion, fruit, veg[4]
	%	
Yellow-headed Amazon *(Amazona ochrocephala ortrix)*	75	100
Forsten's Lorikeet *(Trichoglossus haematodus forsteni)*	62	100
Goldie's Lorikeet *(Trichoglossus goldiei)*	45	83
Blue and Gold Macaw *(Ara ararauna)*	62	80
Scarlet Macaw *(Ara macao)*	62	100
Ring-necked Parakeet *(Psittacula krameri manillensis)*	80	100
Rock Peplar Parakeet *(Polytelis anthopeplus)*	88	80
Blue-crowned Hanging Parrot *(Loriculus galgulus)*	50	75
Total	66	90[5]

[3] Data from 2 y (mean of 44 chicks hatched/y).

[4] Data from 1 y (41 chicks hatched).

[5] Significantly greater than other mean based on Student's *t* test ($p < 0.01$).

Although many birds can be trained to accept pellets as the sole diet, a properly designed extrusion more nearly mimics the physical characteristics of preferred food items. Even so, when an extruded diet was offered with seeds, fruits and vegetables to three adult Timneh African Gray Parrots, seed consumption predominated, as shown in **Table 8**. The parrots were individually housed and were offered weighed amounts of each food item each day for 9 wk. Sufficient quantities were provided so that small amounts of each item were left uneaten. One day per week, the uneaten food was sorted, dried and reweighed. After conversion of the amount of food offered to a dry basis, consumption of each item was calculated from the difference between dry matter offered and dry matter remaining. While consumption of the extrusion varied appreciably, even the highest intakes (22% of dietary dry matter) did not correct the nutrient deficiencies of the seeds that were so highly favored. When nutrient concentrations were estimated for the average intakes shown in **Table 8**, the diet was marginal or deficient in methionine, calcium, available phosphorus, sodium, manganese, zinc, riboflavin, vitamin B-12, available niacin, pantothenic acid, vitamin A and vitamin D.

Because it was apparent that offering an extrusion in a mixture with seeds was not an effective way of meeting nutrient needs, the seeds were gradually withdrawn (over 2-3 d) from food offered to the following five species of psittacines: Green-winged Macaws (*Ara chloroptera*), Yellow-headed Amazons (*Amazona ochrocephala oratrix*), Citron-crested Cockatoos (*Cacatua sulphurea citrinocristata*), Amboina King Parrots (*Alisterus amboinensis*) and Northern Rosellas (*Platycercus adscitus*). One pair (male and female) of each species was housed together and, after a week of feeding a seed-free diet, daily consumption of each food item was determined for 7 d (**Table 9**).

Consumption of the extrusion was much less variable than when it was offered with seeds, and average intake was slightly >80% of dietary dry matter. When this system of dietary husbandry was used, consumption of the other items in the diet did not produce a nutritional imbalance. This was true even though fruit and vegetables comprised nearly 60% of the total dietary fresh weight. The explanation, of course, relates to their high water content and to the fact that they, as well as the extrusion, were good sources of many nutrients. As a consequence, nutrient requirements were met in every instance and dietary fat concentrations were not excessive.

In a broader test of the suitability of this dietary strategy, a comparison was made of the fledging percentage of parent-raised chicks of eight psittacine species whose parents had been fed seeds, fruits and vegetables for 2 y and then were fed an extrusion, fruit and vegetables, but no seeds, for 1 y (**Table 10**). The numbers of chicks hatched per year were not significantly different ($P > 0.05$), but fledging percentage was greatly improved ($P < 0.01$) by the substitution of an extrusion for seeds (90 vs. 66%).

The nutrient specifications for this extrusion are presented in **Table 11**. It may be fed as the sole diet or mixed with fruits and vegetables, as long as it constitutes >=40% of the weight of the diet as fed (wet basis). When calculated on a dry basis, the extrusion should constitute >=80% of the diet.

Table 11

Nutrient specifications for an extruded diet[1]

Nutrient	Concentration	Nutrient	Concentration
	g/kg dry matter		*mg/kg dry matter*
Protein	240	Manganese	65
Arginine	13.0	Zinc	120
Isoleucine	11.0	Iron	150
Lysine	12.0	Copper	20
Methionine	5.0	Iodine	1
Methionine + cystine	9.0	Selenium	0.3
Threonine	9.5	Vitamin K	4
Tryptophan	2.4	Riboflavin	6
Linoleic acid	20	Pantothenic acid	20
Calcium	11.0	Niacin	55
Phosphorus	8.0	Vitamin B-12	0.025
Potassium	7.0	Choline	1700
Sodium	2.0	Biotin	0.3
Chlorine	2.0	Folacin	0.9
Magnesium	1.5	Thiamin	6
	IU/Kg	Pyridoxine	6
Vitamin A	8000		
Cholecalciferol	1900		
Vitamin E	250		

[1] Formulated as a complete diet for psittacines. May be fed with fruits and vegetables but should constitute >=40% of the diet by weight as fed (wet basis) or >=80% of diet dry weight. Ingredients: corn, soybean meal, corn gluten meal, corn hominy feed, alfalfa meal, apple fiber, sucrose, stabilized soybean oil, dicalcium phosphate, calcium carbonate, sodium chloride, L-lysine HCL, ferrous sulfate, copper sulfate, manganous oxide, zinc oxide, calcium iodate, sodium selenite, thiamin mononitrate, riboflavin, nicotinic acid, calcium pantothenate, pyridoxine HCL, monopteroyl glutamic acid, Dbiotin, cyanocobalamin, choline chloride, stabilized ascorbic acid, stabilized retinyl palmitate, D-acitivated animal sterol, dl-alpha-tocopheryl acetate, menadione dimethyl pyrimidinol bisulfite, mold inhibitor, natural colors and natural flavors.

The process of extrusion induces certain physical and chemical changes in the diet that are advantageous (23). The high temperatures destroy microorganisms with pathogenic potential and depolymerize starches that may otherwise be difficult for young birds to digest. By adjustment of the conditions of manufacture, extruded particles of various shape, size and physical texture can be produced.

Questions have been raised in the lay literature concerning the appropriate amount of dietary protein for psittacines, and some have suggested that a protein percentage in the low to mid 20s may be harmful. The implication is that these levels of protein overwork the liver and kidneys and may cause gout.

It is apparent from the earlier discussion that psittacines can be expected to have a typical dietary requirement for protein, and this protein must be well balanced, i.e., it must contain the correct proportions of 10 or more essential amino acids if the birds eating the diet are to be healthy and productive. The data already presented suggest that protein requirements for growth of domestic precocial birds and cockatiels are >=20% of dietary dry matter. This number assumes high protein digestibility and a near-perfect mix of essential amino acids. Earle and Clarke (24) found that the apparent digestibility of protein in white and red millet and in canary grass seed by budgerigars ranged from 72 to 91%. These and other cultivated seeds are generally limiting in lysine and/or methionine.

Protein and amino acid requirements of adult precocial birds tend to be lower than the requirements for growth, but of course, adult precocial birds do not feed their young as do adult psittacines. Whether handfed or parent-fed, the nutrient needs of young altricial birds are presumably the same. Thus, breeding adult psittacines that are raising their young require diets that are adequate to support growth.

Undoubtedly, adult psittacines that are not in a breeding colony or from whom young birds have been removed for hand rearing have lower dietary protein and amino acid requirements. However, the minimum requirements for maintenance of adult psittacines have not been determined. Unfortunately, the adult pet nonbreeding bird is most likely to be fed items that are not nutritionally complete. If appropriately compounded formulated diets are diluted with treats, the nutritional strengths of the formulated diet will help compensate for the nutritional weaknesses of the treats. On the other hand, if formulated diets contain only the minimum maintenance requirements, nutritionally imbalanced treats cannot be regularly fed without endangering health.

What if an adult nonbreeding psittacine is fed only a nutritionally balanced diet, such as the extrusion in **Table 11**, without dilution with other foods? Will its liver and kidneys be overworked and will it get gout? Birds are uricotelic, and uric acid is the principal end product of nitrogen metabolism (25). It is produced in the liver and kidney and is excreted via renal tubular secretion and to some extent via glomerular filtration.The nitrogen in uric acid may come from the diet or from the catabolism of body tissues. Dietary protein in excess of need, poor quality dietary protein (even at low dietary protein concentrations) or low food intake (resulting in tissue catabolism for energy) will increase uric acid excretion in the urine. However, no one has been able to induce primary liver or kidney damage in normal birds by feeding a nutritionally complete diet containing high levels of well-balanced protein. Hasholt and Petrak (26) have described gout in cage birds and note that this is a metabolic disease of obscure etiology. Uric acid and urates are deposited in various tissues instead of being excreted by the kidneys. Studies in some strains of chickens suggest that hyperuricemia and gout may result from genetic impairment of the renal tubular secretory mechanism for uric acid and the site of the defect is the peritubular membrane (27).

Peterson et al. (28) found that susceptibility to articular gout in a selected line of chickens was transmitted as a recessive genetic trait. However, gout was apparent only in susceptible chickens fed an 80% protein diet and was not seen when these chickens were fed 20% protein. In normal chickens, gout was not seen when they were fed either a 20 or 80% protein diet.

Featherston and Scholz (29) and Austic and Cole (30) found that the normal chicken could excrete dietary nitrogen in excess of need, even when dietary protein concentrations were three times the requirement. Plasma uric acid levels did rise, although nowhere near as drastically as they did after >=72 h of fasting (31). The feeding of dietary protein concentrations of 20, 40 and 60% resulted in plasma uric acid concentrations of 480,1130 and

1070 µmol/L (8, 19 and 18 mg/dL), respectively (30). When a 20% protein diet was withheld for 72 h, plasma uric acid rose to µ4160 ~mol/L (70 mg/dL), or ~10 times the initial levels (31). Further fasting (10 d) ultimately produced plasma uric acid concentrations of ~14,870 µmol/L (250 mg/dL). One hour after refeeding the diet, plasma uric acid fell to 830 µmol/L (14 mg/dL) and by 6 h had returned to the base level. Presumably, factors that would limit food intake, such as water deprivation, subordinate social position, infections or specific nutrient deficiencies might produce a similar effect. Even the time of blood sampling in relation to the time of feeding has been shown to alter plasma uric acid concentrations 2- to 3-fold (31).

With respect to nutrient deficiencies, Miles and Featherston (32) found that plasma uric acid concentrations were elevated to 1490 µmol/L (25 mg/dL) when growing chickens were fed 0.6% dietary lysine but fell to ~710 µmol/L (12 mg/dL) as dietary lysine concentrations were raised to the requirement. This increase in plasma uric acid associated with lysine deficiency was a result of catabolism of the other amino acids that could not be used for synthesis of tissue proteins. Such a response is typical of that seen when lysine-deficient seeds comprise most of the diet. If the diet is also deficient in vitamin A, as a seed diet is likely to be, there may be sufficient renal damage to interfere with uric acid elimination, causing an elevation in blood uric acid concentration and resulting in urate deposits in the kidneys and ureters (33). A number of drugs also have been shown to influence uric acid excretion (34, 35). It is apparent, then, that gout in birds is a multifactorial disease. A diet that is deficient in protein, specific amino acids or vitamin A is potentially much more damaging than a properly formulated diet that may provide somewhat more protein than needed for maintenance.

Despite the advantages of a well-formulated diet for psittacines, there are large deviations between the nutrient concentrations of a number of commercial products, advertised as nutritionally complete, and the probable nutrient requirements of birds to which they may be fed. When 11 diets from eight manufacturers were analyzed, both nutrient deficiencies and excesses were revealed (36). Of 18 analytical values for each product, the following nutrients and their indicated concentration ranges (dry basis) were particularly disturbing: (in g/kg) crude protein, 150-310; calcium, 1.8-15.4; phosphorus, 2.9-10.6; calcium/phosphorus ratio, 0.62-1.97; sodium, 0.3-4.1; (in mg/kg) iron, 80-4200; copper, 8-132; zinc, 31-939; manganese, 15- 1055. These ranges include values that are low enough to produce clinical signs of ill health. Notable are the low values for calcium, phosphorus, sodium, zinc and manganese. High values that may lead to clinical signs of toxicity include those for iron, copper, zinc and manganese. An inverse calcium/phosphorus ratio would impact adversely on the metabolism of these two elements. Some of the other extreme values may not produce specific clinical signs but may impair growth and reproduction. Since analyses for amino acids and vitamins were not performed, it is possible that a number of additional nutrients may have been present in deficient or excessive (37) amounts. Thus, it is important that the nutrient specifications of commercial formulated diets be carefully reviewed (and confirmed) before they are used.

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Literature Cited

1. Vriends, M. M. (1984) *Simon and Schuster's Guide to Pet Birds*. Simon and Schuster, New York, NY.
2. Saunders, D. A. (1980) Food and movements of the short-billed form of the White-tailed Black Cockatoo. *Aust. Wildl. Res.* 7: 257-269.
3. Wyndham, E. (1980) Environment and food of the budgerigar *Me1opsittacus udulatus. Aust. J. Ecol.* 5: 47-61.
4. Cannon, C. E. (1981) The diet of Eastern and Pale -headed Rosellas. *Emu* 81:101-110.
5. Snyder, N. F. R., King, W. B. & Kepler, C. B. (1982) Biology and conservation of the Bahama Parrot. *Living Bird* 19: 91-114.
6. Espenshade, E. B., Jr. ed. (1990) *Goode's World Atlas*, 18th ed., Rand McNally, Chicago, IL.
7. Vincent, J. (1966) *Red Data Book*, vol. 2, Aves. Int. Union Conserv. Nat. Resources, Morges, Switzerland.
8. National Research Council (1984) *Nutrient Requirements of Poultry*, 8th rev. ed., National Academy Press, Washington, DC.
9. ROUDYBUSH, T. E. & GRAU, C. R. (1986) Food and water interrelations and the protein requirement for growth of an altricial bird, the cockateil (*Nymphicus hollandicus*). *J. Nutr.* 116: 552-559.
10. GRAU, C. R. & ROUDYBUSH, T. E. (1986) Lysine requirement of cockatiel chicks. *Am. Fed. Avicult. Res. Report* Dec.-Jan., pp. 12-14.
11. HANSON, J. T. (1990) Weight gains and food intakes in hand-raised large parrot chicks, 1984-1986. *Proc. Ann. Conf. Assoc. Avian Vet.*, Phoenix, Az, pp. 75-82.
12. McCarthy, M. A. & Matthews, R. H. (1984) *Composition of Foods: Nut and Seed Products*, Agric. Handbook No. 8-12. Human Nutr. Info. Serv., U.S. Dept. of Agric., Washington, DC.
13. McDaniel, L. (1990) Proximate Analysis of Common Cage Bird Seeds and Applications to the Diet. M.S. Thesis. University of California, Davis, CA.
14. Jones, D. B. (1941) *Factors for Converting Percentages of Nitrogen in Foods and Feeds into Percentages of Proteins*, U.S. Dept. Agric. Circ. No.183, U.S. Dept. Agric., Washington, DC.
15. National Research Council (1988) *Nutrient Requirements of Swine*, 9th rev. ed., National Academy Press, Washington, DC.
16. Young, L. G., Lun, A., Pos, J., Forshaw, R. P. & Edmeades, D. E. (1975) Vitamin E stability in corn and mixed feeds. *J. Anim*. Sci. 40: 495-499.
17. McDonald, S. E. (1990) Anatomical and physiological characteristics of birds and how they differ from mammals. *Proc. Ann. Conf. Assoc. Avian. Vet.*, Phoenix, AZ, pp. 372-389.
18. Ghosh, H.P., Sarkar, P. K. & Guha, B. C. (1963) Distribution of bound form of nicotinic acid in natural materials. *J. Nutr.* 79: 451-453.
19. Combs, G. F., Jr. & Scott, M. L. (1974) Dietary requirements for vitamin E and selenium measured at the cellular level in the chick. *J. Nutr.* 104:1292-1296.
20. Griffiths, T. W. (1961) Studies on the requirement of the young chick for vitamin E. 2. The effects of different sources and levels of dietary lipids on live-weight gain and body vitamin E storage. *Br. J. Nutr.* 15: 271-279
21. Ullrey, D. E. (1974) The selenium-deficiency problem in animal agriculture. In: *Trace Element Metabolism in Animals-2* (Hoekstra, W. G., Suttie, J. W., Ganther, H. E. & Mertz, W., eds.), pp. 275-293, University Park Press, Baltimore, MD.
22. Gottschaldt, K. M. (1985) Structure and function of avian somatosensory receptors. In: *Form and Function in Birds* (King, A. S. & McLelland, J., eds.), vol. 3, pp. 375-496, Academic Press, New York, NY.
23. CAMIRE, M. E., CAMIRE, A. & KRUMHAR, K. (1990) Chemical and nutritional changes in foods during extrusion. Crit. *Rev. Food Sci. Nutr.* 29: 35-57.
24. EARLE, K. E. & CLARK, N. R. (1991) The nutrition of the budgerigar (*Melopsittacus undulatus*). *J. Nutr.* (in press).
25. O'Dell, B. L., Woods, W. D., Laerdal, O. A., Jeffay, A. M. & Savage, J. E. (1960) Distribution of the major nitrogenous compounds and amino acids in chicken urine. *Poult. Sci.* 39: 426-432.
26. Hasholt, J. & Petrak, M. L. (1982) Gout. In: *Diseases of Cage and Aviary Birds* (Petrak, M. L., ed.), pp. 639-645, Lea and Febiger, Philadelphia, PA.
27. Zmuda, M. J. & Quebbemann, A. J. (1975) Localization of renal tubular uric acid transport defect in gouty chickens. *Am. J. Physiol.* 229: 820-825.
28. Peterson, D. W., Hamilton, W. H. & Lilyblade, A. L. (1971) He reditary susceptibility to dietary induction of gout in selected lines of chickens. *J. Nutr.* 101: 347-354.
29. Featherston, W. R. & Scholz, R. W. (1968) Changes in liver xanthine dehydrogenase and uric acid excretion in chicks during adaptation to a high protein diet. *J. Nutr.* 95: 393-398.
30. Austic, R. E. & Cole, R. K. (1972) Impaired renal clearance of uric acid in chickens having hyperuricemia and articular gout. *Am. J. Physiol.* 223: 525-530.
31. Okumura, J. I. & Tasaki, I. (1969) Effect of fasting, refeeding and dietary protein level on uric acid and ammonia content of blood, liver and kidney in chickens. *J. Nutr.* 97: 316-320.
32. Miles, R. D. & Featherston, W. R. (1974) Uric acid excretion as an indicator of the amino acid requirement of chicks. *Proc. Soc. Exp. Biol. Med.* 145: 686-689.
33. Elvehjem, C. A. & Neu, V. F. (1932) Studies in vitamin A avltaminosis in the chick. *J. Biol. Chem*. 97: 71-82.
34. Berger, L., Yu, T. F. & Gutman, A. B. (1960) Effect of drugs that alter uric acid excretion in man on uric acid clearance in the chicken. *Am. J. Physiol.* 198: 575-580.
35. Shideman, J. R., Zmuda, M. J. & Quebbemann, A. J. (1981) The acute effects of furosemide, ethacrynic acid and chiorothiazide on the renal tubular handling of uric acid in chickens. *J. Pharmacol. Exp. Ther.* 216: 441-446.
36. National Research Council (1980) *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington, DC.
37. National Research Council (1986) *Vitamin Tolerance of Animals*. National Academy Press, Washington, DC.