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NUTRITION ADVISORY GROUP
HANDBOOK

FEEDING CAPTIVE INSECTIVOROUS ANIMALS: NUTRITIONAL ASPECTS OF INSECTS AS FOOD[a]

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Insectivory is a term that is sometimes used to refer to the consumption of a wide variety of invertebrate species, including arachnids, annelids and crustaceans, as well as insects. Information in this document is restricted to insects and annelids. Many captive animals will consume invertebrates, live or dead, but it is often necessary to offer live invertebrates (primarily insects) to a variety of fishes, amphibians, reptiles, birds and small mammals. For obligate insectivores, live invertebrates may serve as the primary dietary item. For most species, however, live insects and other invertebrates offer opportunities for behavioral enrichment and can prolong time spent feeding.

To successfully manage captive insectivorous species, data on nutritional composition of invertebrate prey are especially important. Since live insects may be the only food offered to some species, nutritional deficiencies can quickly arise if the nutrient levels in the live prey are imbalanced. Unfortunately, the few commercially available invertebrates are an incomplete nutrient package without appropriate supplementation, and may adversely affect the dietary husbandry of species which consume them as a substantial portion of the their total diet.

Typical laboratory analyses of invertebrates commonly fed in zoos are provided in Tables 1 and 2. Scientific names of these invertebrates are shown in Table 3, and the methods of analysis are summarized in Table 4. Protein concentrations in invertebrate species are relatively high, ranging from 40-70% on a dry matter basis (DMB). Estimates of protein concentration are commonly based on organic nitrogen content multiplied by 6.25 (which assumes protein is 16% nitrogen). However, many invertebrates contain substantial quantities of non-protein nitrogen, from sources such as chitin, which

[a] Adapted in part from Allen, M.E. 1989. Nutritional aspects of insectivory. Doctoral Dissertation, Michigan State University, East Lansing, MI.

may artificially elevate available protein estimates. Chitin, an integral part of the invertebrate cuticle (exoskeleton), can be estimated by determining the acid detergent fiber fraction corrected for ash. Since chitin contains about 7% nitrogen, each 1% of ADF (presumed to be chitin) contains the equivalent of 0.4% crude protein (1 x 0.07 x 6.25). It has been reported, that some insectivores have an intestinal chitinase, while others may rely on chitinases produced by gut microorganisms. Chitin digestibility in three species of mammals has been shown to range from 2-20%. However, there is no evidence that the nitrogen released can contribute to the protein available for absorption by the insectivore.

Ether extract, an estimate of fat, is highly variable among invertebrate species, ranging from 4-55% (DMB), and may vary substantially within a species depending on developmental stage. Many insects accumulate fat during larval development, and two of the most commonly utilized insects in zoos are larval forms, mealworm larvae and wax moth larvae. If these larvae constitute a substantial part of the diet, they may present a disproportionately high fat content, leading to excess energy (caloric) intake relative to other essential nutrients.

Annelids, such as earthworms and night crawlers, are readily available prey items. Generally, these species have less than 20% ether extract (DMB), and contain ample calcium and appropriate calcium to phosphorus ratios (1.5:1 to 2:1). The nutrient composition of annelids is likely to be variable, however, depending on the composition of the substrate (e.g., soil) on which they are grown and/or maintained.

The primary problem in nutrient composition of most insects fed in captivity is that they are poor sources of calcium. The practice of dusting or dipping insects in calcium supplements, even if the insects have been sprayed with cooking spray (said to improve adhesion of supplements), generally provides inconsistent or inadequate levels of calcium and may adversely affect the palatability of the insects. Additionally, if the insects are not consumed immediately, self-grooming or other activity may significantly reduce or eliminate the supplement.

The practice of supplementing crickets with a high calcium diet has been established at many zoos, and the benefits have been documented.[1] An example formulation is shown in Table 5. Commercially manufactured high calcium cricket diets are currently available from the following sources: Marion Zoological, Plymouth, MN 55441, 800-327-7974; Purina Mills, St. Louis, MO 63116, 314-768-4592; Zeigler Bros., Gardners, PA 17324, 800-841-6800. Critical considerations in the use of high calcium diets for crickets are: thorough mixing of feed after shipment and before feeding (minerals may separate), continuous provision of fresh water with no other foods, and maintenance of insects at around 27?C with access to the diet for at least 2-5 days, and no longer than 7-8 days.

Pinhead or subadult crickets, contrary to some reports, are also limited in calcium content (see Table 2). Because pinheads are smaller in size than adult crickets, they may be a more appropriate food choice in some situations. However, they too must be supplemented with calcium. The high calcium cricket diets may be used for pinheads following the same general directions; however, it appears that the diet must be ground extra-fine to accommodate the small mouth parts of emergent crickets.

Researchers have also described dietary methods of increasing the calcium content of mealworm larvae and wax moth larvae. The calcium content and calcium-phosphorus ratio of mealworm larvae were improved by feeding vitamin/mineral supplements.[3] However, similar results may be obtained with more readily applied methods. Feeding mealworm larvae commercially available high calcium cricket diets appears to result in improved calcium content and calcium-phosphorus ratios (see Table 2). The mealworm larvae should be handled in a manner similar to crickets fed the same high calcium diet.

Wax moth larvae also may serve as a source of live food for animals in captivity. Methods for improving their calcium content and calcium-phosphorus ratio have been described.[2] A mixture of honey (12 ml), high protein baby cereal (21.3 g), calcium carbonate (5.7 g), glycerol (10 ml), and water (4 ml) may be prepared. The container in which the diet and wax moth larvae are kept should provide for air circulation. Glass jars with cheese cloth tops and plastic cottage cheese-type containers with air holes punched in the top, in addition to a number of other creative containers, have been used successfully. Although not mentioned in the original publication, the mixture should occasionally (on alternate days) be agitated to prevent caking of the larvae in the diet.

High calcium diets fed to insects intended as prey items are not designed to meet the nutrient requirements of the insect. These diets are intended to fill the insect's gastrointestinal tract and provide a more complete nutrient package for the insectivorous animal consuming the insect. Rotating insects onto the high calcium diet and feeding them out on a regular basis is critical. Extended consumption of high calcium diets (particularly by crickets and mealworm larvae) may lead to high insect mortality.

Insectivorous animals in the wild likely consume a wide variety of invertebrate species. In captivity, we can only reliably provide a limited number of invertebrate species, few of which are good nutrient packages by themselves. Therefore, we have a responsibility to administer a feeding program with supplements that compensate for known shortcomings in the nutrient composition of the invertebrates that are available to us.

Literature Cited

[1] Allen, M.E. and O.T. Oftedal. 1989. Dietary manipulation of the calcium content of feed crickets. J. Zoo. Wildl. Med. 20:26-33.

[2] Strzelewicz, M.A., D.E. Ullrey, S.F. Schafer, and J.P. Bacon. 1985. Feeding insectivores: increasing the calcium content of wax moth (*Galleria mellonella*) larvae. J. Zoo. An. Med. 16:25-27.

[3] Zwart, P. and J. Rulkens. 1979. Improving the calcium content of mealworms. Int. Zoo. Yearb. 19:254-255.

Table 1. Proximate analysis, fiber fraction and energy content of invertebrates (DMB). [abc]

Item	DM	CP	EE	ASH	ADF	GE
	--------------------------------%-----------------------------					kcal/g
Black worm	18.4	47.8	20.1	4.5	0.7	5.57
Blood worm	9.9	52.8	9.7	11.3	*	*
Cockroach, American	38.7	53.9	28.4	3.3	9.4	6.07
Corn borer larvae, European	27.3	60.4	17.2	2.9	13.1	5.69
Corn borer pupae, European	28.0	64.2	17.0	2.6	15.4	5.60
Cricket, domestic, adult	31.0	64.9	13.8	5.7	9.4	5.34
Cricket, domestic, adult, hi-Ca diet	30.3	65.2	12.6	9.8	13.2	5.40
Cricket, domestic, pinhead [d]	47.4	*	*	*	*	*
Earthworm	20.0	62.2	17.7	5.0	9.0	4.65
Fish fly	26.5	63.9	19.5	5.8	10.9	5.88
Fruit fly	29.6	70.1	12.6	4.5	27.0	5.12
Fruit fly larvae	21.2	40.3	29.4	9.8	5.9	5.57
Fruit fly pupae	32.4	52.1	10.5	14.1	17.4	4.84
House fly larvae, dry	93.7	56.8	20.0	6.8	18.0	6.07
House fly pupae, dry	96.4	58.3	15.8	6.8	19.9	5.70
Mealworm beetle	38.6	63.7	18.4	3.1	16.1	5.79
Mealworm larvae	37.6	52.7	32.8	3.2	5.7	6.49
Mealworm pupae	39.0	54.6	30.8	3.4	5.1	6.43
Mealworm larvae, king	40.9	45.3	55.1	2.9	7.2	7.08
Mealworm larvae, king, hi-Ca diet	42.2	38.9	45.4	3.5	7.7	6.79
Mosquito larvae, dry	94.0	42.2	16.1	11.8	*	*
Night crawler	16.3	60.7	4.4	11.4	15.0	4.93
Tubifex worm	11.8	46.1	15.1	6.9	*	*
Water flea, dry	91.7	55.2	6.6	10.8	*	*
Wax moth larvae	34.1	42.4	46.4	2.7	4.8	7.06
Wax moth larvae, hi-Ca diet	39.9	*	*	2.5	*	*

[a] Data provided by Duane E. Ullrey, Comparative Nutrition Laboratory, Michigan State University, and Mary E. Allen, National Zoological Park.

[b] Scientific names of invertebrates provided in Table 3.

[c] Abbreviations and methods of analysis described in Table 4.

[d] Analysis by Covance Laboratories, Inc., Madison, WI 83707; DM in vacuum oven (70?C).

* Value not determined.

Table 2. Major and trace mineral content of invertebrates (DMB). [abc]

Item	Ca	P	Mg	Na	K	Cu	Fe	Zn	Mn	Se
	-----------------%					---------------ppm				
Black worm	0.11	0.85	0.09	0.28	0.98	10	1091	166	16	0.87
Blood worm	0.38	0.90	0.12	0.62	0.35	30	2940	115	22	0.37
Cockroach, American	0.20	0.50	0.08	0.27	0.87	14	90	57	5	0.36
Corn borer larvae, European	0.23	0.64	0.12	0.02	0.05	24	289	90	18	0.31
Corn borer pupae, European	0.22	0.67	0.13	0.02	0.05	20	269	98	16	0.20
Cricket, domestic	0.14	0.99	0.13	0.49	1.29	28	58	188	31	0.58
Cricket, domestic, hi-Ca diet	0.90	0.92	0.11	0.57	1.41	29	80	237	56	0.49
Cricket, domestic, pinhead [d]	0.22	1.27	0.14	0.43	1.62	14	200	268	33	*
Earthworm	1.72	0.90	0.14	0.02	0.06	18	4133	250	142	0.92
Fish fly	0.23	1.07	0.16	0.39	1.01	20	216	378	6	1.63
Fruit fly	0.10	1.05	0.08	0.42	1.06	18	138	171	39	0.07
Fruit fly larvae	0.59	2.30	1.89	0.09	1.28	16	235	176	110	0.49
Fruit fly pupae	0.77	2.73	2.41	0.12	1.66	25	1728	200	108	0.33
House fly larvae, dry	0.41	1.13	0.30	0.72	1.28	50	658	320	167	1.20
House fly pupae, dry	0.42	1.18	0.36	0.55	1.34	54	574	319	302	1.30
Mealworm beetle	0.07	0.78	0.19	0.16	0.92	22	77	113	10	0.29
Mealworm pupae	0.08	0.83	0.23	0.15	0.93	18	42	95	12	0.29
Mealworm larvae	0.11	0.77	0.22	0.14	0.91	19	43	100	14	0.31
Mealworm larvae, king	0.16	0.59	0.12	0.10	0.72	14	59	80	13	0.40
Mealworm larvae, king, hi-Ca diet	0.69	0.57	0.12	0.09	0.88	13	58	86	24	0.18
Mosquito, adult	0.82	1.24	0.33	*	*	76	616	1057	70	*
Mosquito larvae, dry	0.79	1.07	0.21	0.39	0.52	57	3057	281	93	0.57
Night crawler	1.52	0.96	0.16	0.44	0.87	9	1945	1119	29	5.44
Tubifex worm	0.19	0.73	0.09	0.46	0.79	108	1702	190	30	2.16
Water flea, dry	0.10	1.17	0.16	0.98	0.99	39	3049	250	73	1.46
Wax moth larvae	0.11	0.62	0.11	0.05	0.72	9	22	76	3	0.66
Wax moth larvae, hi-Ca diet	0.50	0.33	*	*	*	*	*	*	*	*

[a] Data provided by Duane E. Ullrey, Comparative Nutrition Laboratory, Michigan State University, and Mary E. Allen, National Zoological Park.
[b] Scientific names of invertebrates provided in Table 3.
[c] Abbreviations and methods of analysis described in Table 4.
[d] Analysis by Covance Laboratories, Inc., Madison, WI 83707; Minerals by ICP emission spectrometry.
* Value not determined.

Table 3. Scientific names of invertebrate species in Tables 1 and 2.

Common Name	Genus species
Black worm	*Tubifex* sp.
Blood worm	*Chironomus* sp.
Cockroach, American	*Periplaneta americana*
Corn borer, European	*Ostrinia nubilalis*
Cricket, domestic	*Acheta domestica*
Earthworm	*Allolobophora calignosa*
Fish fly	*Chauliodes* sp.
Fruit fly	*Drosophila melanogaster*
House fly	*Musca domestica*
Krill	*Euphausia* sp.
Mealworm	*Tenebrio molitor*
Mealworm, king	*Tenebrio* sp.
Mosquito	*Aedes* sp.
Night crawler	*Lumbricus terrestris*
Tubifex worm	*Tubifex* sp.
Water flea	*Daphnia* sp.
Wax moth	*Galleria mellonella*

Table 4. Nutrient abbreviations used in Tables 1 and 2, and methods of analysis.

	Abbreviation	Description	Method of Analysis
Proximate analysis	DM	dry matter	Freeze-dried & vacuum oven (60?C)
	CP	crude protein	Nitrogen by Kjeldahl x 6.25
	EE	ether extract (crude fat)	Extraction with diethyl ether
	Ash	total minerals	Combustion overnight at 600?C
	ADF	acid detergent fiber	Detergent digestion/extraction
	GE	gross energy	Bomb calorimetry
Macro minerals	Ca	calcium	Atomic absorption spectrophotometry
	P	phosphorus	Light spectrophotometry
	Mg	magnesium	Atomic absorption spectrophotometry
	Na	sodium	Atomic emission spectrophotometry
	K	potassium	Atomic emission spectrophotometry
Trace minerals	Cu	copper	Atomic absorption spectrophotometry
	Fe	iron	Atomic absorption spectrophotometry
	Zn	zinc	Atomic absorption spectrophotometry
	Mn	manganese	Atomic absorption spectrophotometry
	Se	selenium	Fluorometry

Table 5. Example of a high calcium (8%) diet formulated for crickets.

Ingredient	Percentage by weight
Corn grain, ground	8.3
Alfalfa meal, dehydrated (17% CP)	10.0
Soybean meal, dehulled, solvent extracted (48% CP)	28.7
Wheat, ground	27.0
Calcium carbonate (38-40% Ca)	20.0
Dicalcium phosphate (21% Ca, 18% P)	2.0
Salt	0.5
Mineral premix [a]	0.25
Vitamin premix [b]	0.25
Soybean oil	3.0

[a] Contains per kg: 144g Ca; 0.04g P; 4.3g Mg; 0.6g K; 84.2g Fe; 83.3g Zn; 81.1g Cu; 119g Mn; 0.32g I; and 0.08g Se.

[b] Contains per kg: 28,000,000 IU vitamin A; 2,800,000 IU vitamin D_3; 132,000 IU vitamin E; 0.6g vitamin K_1; 7.1g thiamin; 2g riboflavin; 35.6g niacin; 9.5g D-pantothenic acid; 2g pyridoxine; 1.5g folic acid; 99mg biotin; 6mg vitamin B_{12}; and 190g choline.