Digestibility and Mineral Availability of Phoenix Worms, *Hermetia illucens*, Ingested by Mountain Chicken Frogs, *Leptodactylus fallax*

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Abstract: Soldier fly, *Hermetia illucens*, larvae have been introduced to the herpetoculture market as an alternative, palatable, high-calcium (Ca) foodstuff that minimizes or alleviates the need for additional gut-loading or dust supplements. Long-term successful breeding programs with insectivorous lizards and amphibians fed these larvae have been anecdotally reported; other observations suggest that whole larvae may pass intact and poorly digested through the gastrointestinal tract unless the cuticle is pierced. Feed intake and digestibility trials were conducted with 25 mountain chicken frogs, *Leptodactylus fallax*, housed in groups of five animals fed either crickets, or intact or mashed solider fly larvae to investigate nutrient availability. Diet significantly influenced the digestibility of dry matter, protein, fiber fractions, and all minerals (Ca, phosphorus [P], magnesium, sodium [Na], potassium [K], copper, iron, manganese, molybdenum, and zinc) measured in these trials ($P < 0.01$ for all nutrients), with intact soldier fly larvae lowest in availability. Pureeing the worms increased availability of all nutrients except K and Na compared with intact worms. Both Ca and P digestibilities were approximately doubled in the mashed worms (~90 versus 45–50%) and were similar to values measured in supplemented cricket-based diets. This study suggests that soldier fly larvae can supply high levels of dietary minerals without a need for additional external Ca supplementation, provided target species "chew" their food or in some manner worms are processed to break the exoskeleton.

Key Words: insectivore, nutrition, mountain chicken frogs, *Leptodactylus fallax*, soldier flies, *Hermetia illucens*.

Introduction

A primary health concern for managers of insectivorous amphibian and reptile collections is dietary hypocalcemia. This condition can result from diets deficient in calcium (Ca), diets with an inverse Ca-to-phosphorus (P) ratio (Ca:P), diets deficient in vitamin D_3, or low levels of exposure to ultraviolet B light of proper wavelengths necessary for vitamin D activation (Donoghue and Langenberg, 1996). Ca deficiencies can result in slow growth, failed reproduction, twitching of digits, tetany, incoordination, metabolic bone disease, slow delayed cardiac muscular repolarization, and heart failure (Bennett, 1996; Done, 1996; Murray, 1996; Sabatini *et al.*, 1998). Signs of metabolic bone disease include muscle tremors, spontaneous bone fractures, skeletal deformities, shell deformities, coma, and death (Barten, 1996; Boyer, 1996; Donoghue and Langenburg, 1996). Crickets, *Acheta domesticus*, and mealworm, *Tenebrio molitor* and *Zophobus morio*, larvae comprise important food sources for managed insectivorous species; but, unless treated, they contain inadequate Ca to meet animal requirements (Allen and Oftedal, 1989; Pennino *et al.*, 1991; Barker *et al.*, 1998; Finke, 2002). Strategies for enhancing the Ca content of feeder insects have been reviewed extensively, and optimal results remain equivocal (see Finke *et al.*, 2004, 2005 for reviews of products and techniques; Finke and Winn, 2005). Other higher Ca insects such as silkworm (*Bombyx mori*; Frye and Calvert, 1989; Frye, 1992; Finke, 2002) larvae and stick insects (*Baculum extradentatum* and *Eurycantha calcarata*; Dierenfeld, 2002) also have been suggested as potential dietary sources of this essential nutrient, but feeding trials have not been conducted extensively.

The Phoenix Worm, a trademarked name for larvae of the black soldier fly, *Hermetia illucens*, reared under specific conditions with a proprietary grain-based diet, has recently been introduced to the pet market as a high-Ca alternative feeder insect. *Hermetia illucens* are common throughout most of the Western Hemisphere and the Australian region from Samoa to Hawaii, and the larvae are readily cultured. Advertised as high in nutritional value, particularly in Ca, marketing statements suggest that Phoenix Worms may alleviate the need to gut-load or supplementally dust insects with Ca before feeding to insectivorous animals, and still provide adequate nutritional balance.

Preliminary observations 48 h after a meal of Phoenix Worms fed to a collection of frogs suggested that the majority (estimated >80%), if not all, of the worms were found intact in the fecal material, thus begging the question whether the frogs received any nutritional benefit from the consumption of the diet. As a corollary, might the bioavailability be affected by the feeding behavior of the frogs (i.e., swallowing versus chewing)? The purpose of this study was to evaluate the digestibility and nutrient availability of Phoenix Worms whether presented intact or mashed into a paste.

Materials and Methods

The mountain chicken frog is a large-sized, critically endangered frog found only in the Commonwealth of Dominica and Montserrat. Twenty-five 1-yr-old individuals (mean weight, 123.5±24.7 g/animal; range, 86–199 g) from two clutches were randomly assigned to one of five groups. Weights per group were compared via analysis of variance using Kruskal–Wallis comparisons with SPSS for Windows software (SPSS Inc., 2008), at a significance level of $P=0.05$.

Groups were maintained in 113.60 liters (30-gal) aquariums with a water bowl and no substrate ($n=5$ frogs/group) at 21–26°C (69.8–78.8°F). Animals were fed adult crickets obtained from Timberline Live Pet Foods (Timberline Fisheries, Marion, Illinois) as a baseline (control) diet. Before and throughout the 11-day study, crickets were fed a commercial cricket diet (Cricket Power Food, Timberline Fisheries) and dusted with Rep-Cal Phosphorus-Free Calcium with Vitamin D3 Ultrafine Powder (Rep-Cal Research Labs, Los Gatos, California) immediately before being fed to frogs. Phoenix Worms were obtained from Worm Man (www.wormman.com).

Two weeks of habituation was allowed before the feeding study began. Every other day, each group of frogs was moved to a "clean" cage and then fed. Previous observations had shown that within 48 h, all fed items would be excreted, primarily into the water containers (King, unpublished data).

On day 1 of the study, each group of frogs was fed a total of 200 live medium-sized Phoenix Worms, with a mean meal weight of 9.72 g. Within 24 h, all worms had been consumed. Frogs were moved to new aquaria on days 3, 5, 7, 9, and 11. On day 9, each frog was tube-fed 40 Phoenix Worms that had been ground with mortar and pestle and made into a slurry (200 worms/tank; 9.7 g, fresh weight). All water and waste were collected from individual aquaria and frozen on days 3 and 11, corresponding to dietary Phoenix Worm treatments.

As control and "wash-out" diets, frogs were fed 30 crickets per group, average weight 13.30 g, before and between Phoenix Worm trials. Fecal remains were collected and pooled for days 5, 7, and 9, corresponding to cricket meals on days 3, 5, and 7, respectively.

Frozen samples of feeds, and water containing all fecal remains were submitted for nutrient analysis. Water was evaporated at 60°C, and all dry matter recovered was scraped from glass drying pans, weighed, and sent for crude protein, fiber (neutral and acid detergent fiber; NDF and ADF, respectively, as measures of dietary "fiber"; Finke, 2002) and mineral analysis (Dairy One Forage Lab, Ithaca, New York).

Apparent digestibility was calculated by determining dry matter (DM) intake and excretion using the following formula:

$$Da = \frac{Fi - Pt}{Fi}$$

where Fi is the average daily DM intake, and Pt is the average quantity of undigested DM voided daily. Partial digestion coefficients were calculated for crude protein, NDF and ADF, and various minerals using proportional composition of feed and fecal DM. Each group of five frogs was treated as a single sampling unit, with intake and fecal output data pooled per tank for chemical analysis and evaluation.

Digestibility data were not normally distributed nor could they be appropriately transformed; hence, nonparametric statistics were used to assess differences of dietary treatments at a P level of 0.05 for significance (Kruskal–Wallis test) using SPSS for Windows software (SPSS Inc., 2008).

Results

No differences in mean weights of the frogs were observed among groups over the trial period (one-way analysis of variance; $F=2.87$, $P>0.05$); frogs averaged 124.44±24.86 g ($\bar{X}\pm SD$; range, 86–202 g). When fed Phoenix Worms, frogs ate from 1.3% to 1.8% of body weight (fresh weight; corresponding to 0.4–0.5% DM intake). Frogs consuming crickets ate a daily amount between 1.8% and 2.4% of body weight in this trial; on a DM basis, this amounted to 0.6–0.8% of body weight. Composition of diets and feces are presented in Tables 1 and 2, respectively, and digestion coefficients are presented in Table 3.

Diet significantly influenced the digestibility of all nutrients measured in these trials ($P<0.01$ for all nutrients). Dry matter and crude protein digestibility were significantly lower in intact Phoenix Worms compared with other diets ($F=12.522$, $P=0.002$). Fiber digestibility also differed significantly among diets ($F=10.519$, $P=0.005$ for NDF; $F=12.522$, $P=0.002$ for ADF), with the intact Phoenix Worms being the lowest. Apparent Ca digestibility was similar in the Phoenix Worm paste and crickets and lowest for intact Phoenix Worms ($F=10.238$, $P=0.006$). P, copper (Cu), manganese (Mn), molybdenum (Mo), and zinc (Zn) digestibilities were also higher in the crickets and worm puree compared with intact Phoenix Worms ($F=11.601$, $P=0.003$ for P and Mn; $F=10.519$, $P=0.005$ for Cu; $F=12.042$, $P=0.002$ for Mo; $F=9.437$, $P=0.009$ for Zn). Crickets were highest in potassium (K) ($F=11.601$, $P=0.003$) and sodium (Na) digestibilities; Na digestibility was negative for both Phoenix Worm treatments ($F=11.200$, $P=0.004$). Magnesium (Mg) and iron (Fe) were significantly better digested in mashed Phoenix Worms compared with crickets or intact worms ($F=6.672$, $P=0.036$ for Mg; $F=9.397$, $P=0.008$ for Fe). Three of the five trace minerals evaluated demonstrated negative digestibility coefficients in frogs fed intact Phoenix Worms.

Discussion

By chemical analysis (Table 1), soldier fly larvae seem to be an excellent potential prey species for insectivores, containing high levels of protein, moderate dietary "fiber" concentrations, and generally higher concentrations of minerals compared with more typical insects used in managed feeding programs. In particular, the Phoenix Worms contained 1.4 (P) to 16.5 (Ca) times higher levels of various elements compared with published values of cricket composition; only Na concentration was lower. These high levels of Ca, Mg, Fe, and Mn in the larvae, combined with low levels of Na, reflect mineral profiles commonly found in temperate green forages (Zootrition® Dietary Analysis software, version 2.6, Saint Louis Zoo, St. Louis, Missouri) as well as some food substrates of adult soldier flies (herbivore manure; Newton *et al.*, 2005; Dierenfeld, unpublished data).

Clearly, however, the physical condition of the soldier fly larvae themselves can influence availability and digestibility of all aspects of the diet, as demonstrated by chicken frogs in this study, and thus may limit the usefulness of Phoenix

Table 1. Composition of crickets or Phoenix Worms, *Hermetia illucens* larvae, fed to chicken frogs, *Leptodactylus fallax*. All nutrients except water presented on a dry matter basis.

Nutrient	Supplemented crickets (this study)	Unsupplemented crickets (Zootrition 2.6)[a]	Phoenix Worms (this study)	Phoenix Worms (supplier info)[b]
Water, %	65.2	71.1±2.3	73.2	NA[c]
Crude protein, %	66.1	65.1±1.0	57	64.6
Neutral detergent fiber, %	22.1	20.6±1.5	20.7	NA
Acid detergent fiber, %	10.4	9.9±0.7	12.6	NA
Ca, %	4.18	0.16±0.04	3.14	3.04
P, %	0.79	0.91±0.11	1.28	2
Ca:P	5.3:1	1:5.7	2.5:1	1.7:1
Mg, %	0.12	0.11±0.03	0.79	NA
K, %	1.03	1.21±0.12	1.96	NA
Na, %	0.41	0.46±0.04	0.27	NA
Cu, mg/kg	19	18.9±9.8	17	NA
Fe, mg/kg	119	77.7±30.1	368	NA
Mn, mg/kg	56	32.7±4.1	364	NA
Mo, mg/kg	0.8		1.0	NA
Zn, mg/kg	144		242	NA

[a] Summarized data: Zootrition Dietary Analysis software, version 2.6, Saint Louis Zoo.
[b] www.wormman.com (as-fed data from supplier, converted to dry basis for comparison, using moisture content determined in this study).
[c] NA = not available.

Worms as a food item. All adult amphibians are primarily carnivorous; ingested food is fragmented partially by teeth and then further broken down by passage through a relatively short and simple gastrointestinal tract (Stevens, 1988). Hydrochloric acid secreted in the stomach inhibits bacterial activity, hastens the death of still-living prey, and initiates the decalcification of bone. The mechanical breakdown of the integument, including the sclerotized exoskeleton, allows the entry of digestive enzymes into the soft tissues of prey (Duellman and Trueb, 1986; Wright, 2001). The exoskeleton of the Phoenix Worm seems impervious to typical digestive processes in chicken frogs, and possibly other amphibian species, if not pierced. As with other amphibians, size of prey offered may thus be a critical element of the feeding regimen to ensure proper breakdown mechanisms. It is possible that larger larvae may have been more suitable as food for these larger bodied frogs compared with the size used in this study.

Although crickets and larvae in this study contained similar crude protein and fiber amounts, DM and protein digestibility of crickets were superior to that of soldier fly larvae. Some nitrogen (protein) has been shown to be chemically bound in the exoskeleton of feeder insects (Pennino *et al.*, 1991; Finke and Win, 2005). Thus, unavailable protein may underlie differences seen in crude protein digestibility of the larvae, with even cuticle-bound protein being better exposed to endogenous enzyme activity and digestive acids in the macerated larvae. However, the level of chemically bound protein is generally $<10\%$ of total protein, a much smaller proportion than would explain the wide variability observed in this trial. The reduced digestibility of crude protein in Phoenix Worms eaten by mountain chicken frogs (compared with crickets) may result in poorer use as has been shown by slower growth in feeding trials with fish (Bondari and Sheppard, 1981), another simple-gutted poikilotherm. In the fish trials, chopping of the larvae improved weight gain and efficiency. Cricket protein digestibility by chicken frogs in this study (95%) is similar to ranges reported for Mormon cricket, *Anabrus simplex*, meal fed to poultry and rats (Defoliart *et al.*, 1982; Finke *et al.*, 1987), suggesting differences in protein quality between the two invertebrate species investigated.

Apparent digestibility of dietary fiber fractions—probably not true chitin but rather a laboratory artifact—was considerably higher than expected for a small animal with a simple digestive tract and no microbial fermentation ability (Stevens, 1988). Although it has been reported that amphibians do not possess enzymes to facilitate breakdown of keratin, chitin, or cellulose (Reeder, 1964), more recent investigations have documented chitinases in some anurans (Fujimoto *et al.*, 2002). Thus, endogenous or microbial chitinase (or similar) enzymes may be present in the gastrointestinal milieu of mountain chicken frogs to assist with breakdown of this carbohydrate constituent, but this has

Table 2. Composition of feces from chicken frogs, *Leptodactylus fallax*, fed exclusive diets of crickets, *Acheta domestica*, or Phoenix Worm, *Hermetia illucens*, larvae. All nutrients presented on a dry matter basis.

Nutrient	Cricket diet fecals	Whole Phoenix Worm diet fecals	Mashed Phoenix Worm diet fecals
Crude protein, %	22.7	43.5	56.4
Neutral detergent fiber, %	47.4	39.2	18.5
Acid detergent fiber, %	41.6	24.5	14.0
Ca, %	4.81	2.38	1.65
P, %	0.36	0.84	0.51
Mg, %	0.77	1.00	2.01
K, %	1.94	2.02	3.28
Na, %	2.79	1.76	6.76
Cu, mg/kg	55.0	37.0	36.0
Fe, mg/kg	3,750.0	1,910.0	925
Mn, mg/kg	114.0	205.0	109
Mo, mg/kg	2.9	1.8	2.9
Zn, mg/kg	312.0	280.0	318

not been studied previously in this species. Substantial disappearance of dietary "fiber" suggests the presence of some physiological mechanism. The apparent negative digestibility of fiber components by frogs eating intact Phoenix Worms further implies a laboratory analytical artifact in determination of these constituents; a need for appropriate enzyme activity for breakdown, which may be blocked by an intact exoskeleton in the larvae; or both.

Regarding minerals, although specific nutrient requirements for reptiles and amphibians have not been experimentally derived, general dietary macromineral recommendations established for domestic carnivores and birds (Ca, 0.4–1.2%; P, 0.3–0.6%; Mg, 0.03–0.1%; K, 0.2–1.4%; and Na, 0.05–0.4% as a percentage of DM; NRC, 1985, 1986, 1994) may be suitable guideline levels for carnivorous/insectivorous herps. There also seems to be a maximum tolerable for each of these nutrients (~5% for Ca for indeterminate layers and ~0.8–1.0% for P; NRC, 1980). Both Ca and P levels in Phoenix Worms are above the ranges suggested as optimal, and the Ca:P ratio measured (2.5:1) is higher than the optimal range for dietary Ca:P (1:1–2:1) suggested for insectivores (Allen and Oftedal, 1989). The supplemented crickets in this study, however, contained even more skewed ratios of Ca to P than the soldier fly larvae, with a Ca:P ratio of 5.3:1. Supplementation (gut-loading and dusting), in this case, was successful in raising Ca levels (see the comparison between supplemented and unsupplemented cricket composition in Table 1) but may have actually been excessive, leading to possible other mineral imbalances.

Dietary Mg recommendations established for most vertebrates range from ~0.04% to ~0.2% DM; higher quantities

Table 3. Digestibility coefficients from chicken frogs, *Leptodactylus fallax*, fed exclusive diets of crickets, *Acheta domestica*, or Phoenix Worm, *Hermetia illucens*, larvae. $n = 5$ groups of frogs fed each diet.

Nutrient	Cricket diet	Whole Phoenix Worm diet	Mashed Phoenix Worm diet
Dry matter, %	86.08 ± 4.01^a	26.00 ± 9.88^c	76.31 ± 3.16^b
Crude protein, %	95.22 ± 1.38^a	43.53 ± 7.54^c	76.56 ± 3.12^b
Neutral detergent fiber, %	70.14 ± 8.60^a	-40.47 ± 18.75^b	78.77 ± 2.83^a
Acid detergent fiber, %	44.31 ± 16.04^b	-43.66 ± 19.17^c	73.72 ± 3.50^a
Ca, %	83.98 ± 4.61^a	43.911 ± 7.49^b	87.55 ± 1.66^a
P, %	93.66 ± 1.83^a	51.44 ± 6.48^b	90.56 ± 1.26^a
Mg, %	10.66 ± 25.73^b	6.33 ± 12.50^b	39.72 ± 8.03^a
K, %	73.78 ± 7.55^a	23.73 ± 10.18^c	60.35 ± 5.28^b
Na, %	5.88 ± 27.10^a	-378.01 ± 63.79^b	-488.56 ± 78.38^b
Cu, mg/kg	59.70 ± 11.61^a	-61.06 ± 21.49^b	49.83 ± 6.68^a
Fe, mg/kg	-338.75 ± 126.36^b	-284.08 ± 51.26^b	40.45 ± 7.93^a
Mn, mg/kg	71.66 ± 8.16^b	58.32 ± 5.56^c	92.91 ± 0.94^a
Mo, mg/kg	49.53 ± 14.54^a	-125.84 ± 55.56^b	22.61 ± 9.64^a
Zn, mg/kg	69.83 ± 8.69^a	22.97 ± 10.28^b	71.99 ± 3.73^a

Different superscript lowercase letters in rows differ significantly ($P < 0.05$, Kruskal–Wallis test).

can interfere with Ca absorption (NRC, 1980). Conversely, high Ca also can interfere with Mg uptake and use. In this study, crickets were within the optimal dietary range for Mg, whereas Phoenix Worms contained considerably higher Mg levels. The low digestibility of Mg in mountain chicken frogs fed all dietary treatments may result from excess dietary Ca, particularly so for the cricket diet; limited availability of Mg, especially in worms with intact cuticles; or a combination of both factors.

The K levels in both Phoenix Worms and crickets are well above dietary recommendations established for other livestock and companion species (0.3–0.65% DM), approaching levels considered maximum tolerable allowances (NRC, 1980). Alternatively, Na concentrations in diets were low by comparison with needs for other species (~0.4% DM); very low and negative digestion coefficients suggest that electrolyte balance may have been impaired by these dietary treatments fed to mountain chicken frogs. In particular, the Phoenix Worm diet may have induced a "diarrhea"-type effect leading to hyponatremia; physiologic parameters would need to be measured to confirm this speculation. If the worms do cause some type of gut irritation, long-term physical effects would probably be seen in the condition of consumers; such effects have not been reported for any species. More likely, the short-term (1-day) feeding treatment may have not been representative of a steady-state condition; however, this may nonetheless approximate a practical mixed feeding regimen used by many herpetoculturists.

Dietary requirements for Cu (DM basis) are estimated to be ~3 mg/kg for dogs, 5 mg/kg for cats, and 8 mg/kg for chickens, whereas Fe requirements of the above species range from 32 mg/kg to 110 mg/kg and recommended dietary levels of bioavailable Zn are 10–50 mg/kg DM (NRC, 1985, 1986, 1994). Trace minerals were found at substantially higher concentrations in both Phoenix Worms and crickets in this study, suggesting there may be little or no need for additional dietary supplementation of these particular nutrients. In fact, some whole invertebrate prey may contain inappropriately high levels of Fe for individuals with a tendency to develop Fe-storage disease. Elevated excretion and the observed negative digestibility of iron may possibly be explained by chemical chelation effects of dietary fiber in the worms; a physical scraping effect in the intestine such that cell walls were excreted as well, with animal tissue Fe (or even blood) increasing elevating Fe content of the feces; or a combination. Estimated Mn needs of dogs and cats (5 mg/kg dietary DM) as the model for insectivorous herps would probably be met by most whole insect prey. The issue of bioavailability may be relevant; poor availability of Mn in some plant products is responsible for the elevated requirement of this nutrient in natural-ingredient chicken diets (from 15 mg/kg to up to 66 mg/kg DM; NRC, 1994), but the Mn requirement of carnivorous birds has not been determined. High dietary Zn increases the synthesis of the intestinal protein metallothionein, which binds certain metals and prevents their absorption by trapping them in intestinal cells. Metallothionein has a stronger affinity for Cu than for Zn; so, high levels of metallothionein induced by excess Zn may have caused a decrease in intestinal Cu absorption.

Regardless of mechanism, trace mineral availability seems to have been affected by physical presentation of the Phoenix Worms, with Cu, Fe, Mn, Mo, and Zn significantly reduced in intact larvae compared with those that had been mashed before feeding. As well, trace mineral digestibilities were the same or higher in mashed Phoenix Worms compared with crickets. Interestingly, Fe showed negative digestibility for both the cricket and intact Phoenix Worm diet treatments. Although Fe has been shown to be chemically chelated by dietary "fiber," which can reduce bioavailability, the fiber fractions measured in this study were similar between the Phoenix Worms and the crickets (Table 1); hence, that effect may be unlikely in this case. It is possible that minerals were chemically bound in the sclerotinized cuticle, but localization of the elements was not determined specifically. It is also possible that trace mineral balance was affected by water mineral content, which was not measured in this study. Such effects, however, would have carried across all dietary treatments if present.

The original impetus for this study was to investigate dietary mineral availability from soldier fly larvae as a feed source for an insectivorous frog. Soldier flies are readily cultured in biological materials and used for livestock manure waste management programs (Newton *et al.*, 2005). Coprophagous species often consume diets containing high mineral loads and as such may be expected to have evolved mechanisms for efficient use, deposition/sequestering of these resources, or a combination. The Phoenix Worms used in these trials were raised on a commercial grain-based diet designed to support maximal production and nutritional content. Regardless of rearing method, either the gut contents of the larvae, the exoskeleton, or both may contain higher elemental concentrations than many feeder insects, and a higher Ca:P ratio, although it seems that minerals are poorly available if the worms are not macerated in some manner by the consumer.

This study suggests that Phoenix Worms can supply high levels of dietary minerals without a need for additional Ca supplementation but perhaps are limited to species that "chew" their food and may be less useful for species that swallow their food whole, possibly limiting their application in ranaculture. Alternatively, if the worms are processed in some manner first to break the exoskeleton, a larger size is fed such that worms are manipulated and partially crushed in the mouth (such as with the crickets), or both, they may provide another suitable alternative feed high in minerals—even for frogs—without a need for additional dietary supplementation. Soldier fly larvae have been successfully used in captive feeding and breeding programs for many lizard species (Sheppard, personal communication), and the worm meal has been used as a protein source in fish and bullfrog (*Rana* spp.) farming.

Last, cost may be a factor to consider. In this study, cost was $3.98/feeding/frog for Phoenix Worms compared with from $0.07 to 0.13/feeding/frog for crickets—a 40-fold difference. Larger worms, however, would have been more economical in the feeding trials, and or a better supplier pricing could have been obtained from a different source, dropping the price difference considerably. A combination of both foodstuffs may be most optimal, both nutritionally and economically. Further studies, with a variety of both reptile and amphibian species, are suggested to confirm the findings of this study.

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