Larval Protein Quality of Six Species of Lepidoptera (Saturniidae, Sphingidae, Noctuidae)

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ABSTRACT Six lepidopteran species representing three families were evaluated for their potential use as protein supplements for poultry. Proximate and amino acid analyses were conducted on larval powders of each species. Larvae ranged from 49.4 to 58.1% crude protein on a dry-weight basis. Amino acid analysis indicated deficiencies in arginine, methionine, cysteine, and possibly lysine, when larvae are used in chick rations. In a chick-feeding trial with three of the species, however, these deficiencies were not substantiated: the average weight gained by chicks fed the lepidopteran-supplemented diet did not differ significantly from that of chicks fed a conventional corn/soybean control diet.

LEPIDOPTERA ARE among the many species of insects that have played an important role in nutrition, especially in areas where human and domestic animal populations are subject to chronic protein deficiency (e.g., Bodenheimer 1951, Quin 1959, Ruddle 1973, Conconi and Bourges 1977, Malaise and Parent 1980, Conconi et al. 1984). Conconi et al. (1984), for example, listed 12 species in 8 families that are gathered and consumed in Mexico. Wider utilization of Lepidoptera as domestic animal feedstuffs has probably been precluded by the difficulties inherent in gathering them in sufficient quantities on a regular basis. Pupae of the silkworm, *Bombyx mori* (L.), however, available as a byproduct of the silk industry, have been used not only as human food but as a high-protein supplement for poultry in parts of Asia. Ichhponani and Malek (1971) reported the annual production of de-oiled silkworm pupae in India alone at 20,000 metric tons.

Proximate analyses (percent protein, moisture, fat, ash, crude fiber, and carbohydrate) have been conducted on larvae or pupae of species in a number of families of Lepidoptera (Quin 1959, Conconi and Bourges 1977, Malaise and Parent 1980, Conconi et al. 1984). Crude protein content was found to range from 7.8 to 11.8% in samples of freshly killed larvae to between 50 and 80% in larval samples subjected to various degrees of dehydration. By contrast, amino acid profiles are available only for pupae of *B. mori* (Bombycidae) (Chopra et al. 1970, Wijayasinghe and Rajaguru 1977) and larvae of *Xyleutes redtenbachi* (Hammerschmidt) (Cossidae), a species utilized as human food in Mexico (Conconi and Bourges 1977). We are not aware of any laboratory studies involving Lepidoptera fed to rats to determine bioavailability of amino acids; only in the case of *B. mori* pupae has amino acid analysis been followed by feeding trials on poultry (Ichhponani and Malek 1971, Wijayasinghe and Rajaguru 1977).

To determine and compare the protein quality of a wider assortment of lepidopterous larvae, we conducted proximate and amino acid analyses on larvae of six species representing three families. These included the cecropia moth, *Hyalophora cecropia* (L.), and the promethea moth, *Callosamia promethea* (Drury), in the family Saturniidae; the tobacco hornworm, *Manduca sexta* (L.), in the family Sphingidae; and the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), southern armyworm, *S. eridania* (Cramer), and the armyworm, *Pseudaletia unipuncta* (Haworth) in the family Noctuidae. Chick feeding trials were conducted with dry powders of the sphingid and saturniid larvae. Although our primary interest was in the noctuid species because of their gregarious nature and potential for opportunistic mass harvest of wild populations, we were unable to accumulate enough noctuid powder for a feeding trial.

Materials and Methods

Source and Rearing of Experimental Insects

Saturniidae. *H. cecropia* pupae were obtained from J. M. Scriber (Department of Entomology, University of Wisconson–Madison). Adults emerged and mated; eggs were collected and placed in plastic crispers (30 by 12.7 by 6.4 cm) provided with fresh *Prunus serotina* (Ehrhart) (black cherry) foliage. A total of 800 g of dried *H. cecropia* was produced for a chick feeding trial. *C. promethea* were also reared on *P. serotina* foliage. Totally, 350 g of dried *C. promethea* were prepared for a chick feeding trial.

Sphingidae. *M. sexta* larvae were obtained from the laboratory colony of W. G. Goodman (Department of Entomology, University of Wisconsin–Madison). Some of these larvae were reared on artificial diet (Bio-Serv Tobacco Hornworm diet

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Table 1. Proximate analysis of fifth-instar lepidopteran larval powders compared with conventional protein supplements

Protein source	Protein (%)	Moisture (%)	Fat (%)	Ash (%)	Crude fiber (%)	Carbohydrates (%)	Calories/100 g
Fish meal (menhaden)	60.5	8.0	9.4	—	0.7	—	282
Soybean meal (dehulled)	48.5	10.0	1.0	—	3.9	—	244
Meat and bone meal	50.4	7.0	8.6	—	2.8	—	196
H. cecropia	54.7	2.6	10.2	5.9	14.7	12.0	358
C. promethea	49.4	4.5	10.0	6.9	10.8	18.4	361
M. sexta[a]	58.1	4.7	20.7	7.4	9.4	>0.1	418
M. sexta[b]	57.8	4.7	16.5	8.1	8.4	4.5	398
S. frugiperda[a]	57.8	2.1	20.2	5.6	6.7	7.7	443
S. frugiperda[b]	57.2	3.6	11.3	11.2	12.0	4.8	349
P. unipuncta	54.4	2.0	14.9	6.9	5.0	15.7	424
S. eridania	54.7	4.5	13.9	9.8	7.1	10.0	384

[a] Reared on artificial diet.
[b] Reared on fresh plant material.

No. 9783); others were reared on *Solanum dulcamara* (L.) (nightshade).

Noctuidae. *S. frugiperda* were obtained from John Young (USDA Laboratory, Tifton, Ga.). They were fed a variation of the diet formulated by Shorey and Hale (1965). The colony of *S. eridania* was obtained from J. M. Scriber and fed the same artificial diet. *P. unipuncta* adult females were collected in the field. Eggs were laid, and emerging individuals were fed artificial diet or *Agropyron repens* (L.) (quack grass).

Methods of Biochemical Analysis

All insects were harvested in the final instar or prepupal stage. They were frozen at −23°C, and lyophilized. The coarse-ground larvae were reduced to a powder in a Wiley Mill using a 20-mesh screen. Proximate analyses were performed using procedures described by the Association of Official Analytical Chemists (Anonymous 1945). Amino acid profiles were obtained by acid hydrolysis of the powders and subsequent analysis on an amino acid analyzer (Beckman).

Method of Chick Bioassay

The chemical analysis was followed by a biological assay. Three powders, *H. cecropia. C. promethea,* and *M. sexta,* were tested as the protein supplement in a corn-based diet. All diets were based on the most recent National Academy of Science–National Research Council (NAS–NRC) recommendations (National Research Council 1977). They were isonitrogenous and isocaloric. There was no information on the vitamin content of the various powders; thus, all necessary vitamins were added as a supplement as prescribed by NAS–NRC. The availability of the minerals also was unknown and all required minerals were added. This supplementation allowed comparisons of the

Table 2. Amino acid profiles of lepidopterous larvae compared with dietary requirements for chickens and 44% soybean meal

Amino acid mg/g of protein	Requirement for: Broiler chick	Requirement for: Laying hen	Soybean meal (44%)	*H. cecropia*[a]	*C. promethea*[b]	*M. sexta*[a]	*M. sexta*[b]	*S. frugiperda*[a]	*P. unipuncta*[a]	*S. eridania*[b]
Arginine	63	53	75	53	42	53	42	67	54	40
Glycine-serine	65	33	108	208	184	105	90	100	102	105
Histidine	15	15	26	27	29	37	41	38	29	31
Isoleucine	35	33	54	33	29	43	37	44	38	45
Leucine	59	80	80	51	44	68	62	77	64	72
Lysine	52	40	67	44	43	71	81	77	180	74
Methionine	22	18	15	14	10	18	20	24	23	21
Methionine-cysteine	40	33	30	22	15	26	26	31	36	28
Phenylalanine	31	27	52	43	34	47	42	49	39	41
Phenylalanine-tyrosine	58	53	81	140	114	113	93	128	93	79
Threonine	33	27	41	41	39	41	36	51	46	53
Tryptophan	10	7	14	NA	NA	NA	NA	NA	NA	NA
Valine	36	33	53	45	41	66	56	52	47	58

NA, not attempted.
[a] Reared on artificial diet.
[b] Reared on fresh plant material.

Table 3. Composition of experimental diets fed to chicks

Ingredient (% of diet)	Diet 1 (Control)	Diet 2 (*H. cecropia*)	Diet 3 (*C. promethea*)	Diet 4 (*M. sexta*)
Ground corn	55.75	62.95	52.80	64.50
Soybean meal (44%)	28.00			
Wheat middlings	5.00			
Alfalfa meal (17%)	3.00			
Meat meal	3.00			
Insect meal		30.20	37.20	30.04
Iodized salt	0.50	0.40	0.40	0.40
Dicalcium phosphate	0.75	2.57	3.12	3.00
$CaCO_3$	1.00	0.80	0.50	0.60
$MnSO_4$		0.03	0.03	0.03
$ZnCO_3$		0.01	0.01	0.01
Fe citrate		0.04	0.04	0.04
Se Premix:				
(1 mg Se/g NaCl)		0.01	0.01	0.01
Corn oil		2.40	5.00	1.00
Choline (50%)		1,300 mg/kg	1,300 mg/kg	1,300 mg/kg
Vitamin mix	3.00[a]	0.50[b]	0.50	0.50
Vitamin E		20 IU/kg	20 IU/kg	20 IU/kg
Amino acid supplementation (mg/g protein)				
Arginine		38	58	48
Isoleucine		10	19	—
Leucine		—	15	—
Lysine		42	46	46
Methionine		40	60	38

Only half the chicks fed diets 2 and 4 received the amino acid supplementation.
[a] Vitamin mix diluted with wheat middlings used in the standard diet by the Department of Poultry Science, University of Wisconsin, Madison.
[b] Vitamin mix designed to fulfill requirements of NAS–NRC.

diets that more accurately reflected protein quality.

The chicken feeding trials were designed for the limited amount of protein powder available. Use of New Hampshire × white leghorn chicks allowed a more sensitive test due to their lower feed consumption. Twenty-eight 1-day-old chicks were assigned to four treatments in a stratified random block design. For each treatment, eight birds were banded, individually weighed, and placed in electrically heated chick starter wire cages. Four chicks were used in the *C. promethea* treatment because of the relatively small amount of *C. promethea* powder available. Food and water were provided ad lib. The birds were weighed on alternate days.

After 8 days, each treatment was divided. Half the chicks continued to eat the same diet and half received the diet supplemented with amino acids to meet NAS–NRC recommendations. All of the *C. promethea* diet was supplemented because of the limited supply. Mean weight gains for the chicks fed the various diets were compared by analysis of variance.

Results and Discussion

In the proximate analysis, the crude protein content of the lepidopteran powders was comparable with that of the conventional protein feed supplements, fish meal, meat and bone meal, and

Table 4. Mean weights and feed/gain ratios of chicks fed experimental diets

Protein source	18 days				21 days			
	Wt $\bar{x}$ (±SD) (g per bird)	Feed consumed (g per bird)	Wt gained (g per bird)	Feed/gain ratio	Wt $\bar{x}$ (±SD) (g per bird)	Feed consumed (g per bird)	Wt gained (g per bird)	Feed/gain ratio
Soybean meal (control)	137 (14.2)	232	99.9	2.32	167 (15.0)	326	129.3	2.52
Soybean meal (control)	131 (27.3)	240	93.9	2.56	158 (32.7)	364	120.3	3.03
C. promethea[a]	120 (15.0)	196	82.0	2.39	NT	NT	NT	NT
M. sexta	127 (14.8)	210	89.1	2.36	150 (15.5)	285	112.6	2.53
M. sexta[a]	121 (9.4)	194	83.1	2.33	154 (6.6)	267	115.6	2.31
H. cecropia	122 (34.0)	225	84.6	2.66	145 (44.6)	282	106.6	2.65
H. cecropia[a]	141 (22.8)	233	103.1	2.26	180 (21.7)	292	142.6	2.05

NT, not tested.
[a] Diet with supplemental amino acids.

soybean meal. The six species had a range of from 49.4 to 58.1% crude protein on a dry-weight basis (Table 1). This compares with ca. 58% found in the Mormon cricket (*Anabrus simplex* Haldeman) (DeFoliart et al. 1982), but is somewhat lower than percentages reported for many insects, including some other species of Lepidoptera. A 71% protein content was reported by Conconi and Bourges (1977) for larvae of *X. redtenbachi*, and a protein content of 63.3% has been reported for silkworm pupae (74–76% for de-oiled pupae) fed to poultry in Asia (Bora and Sharma 1965, Chopra et al. 1970, Wijayasinghe and Rajaguru 1977).

The proximate analyses indicated that the fat and, thus, energy content were higher in the insect powders than in the conventional supplements in all cases (Table 1). The extremely high fat content of *M. sexta* and *S. frugiperda* that were fed on the artificial diet probably reflects the diet on which they were reared and the fact that not all larvae were able to clear the gut before they were harvested.

The amino acid profiles (Table 2) indicated deficiencies in arginine, methionine, cysteine, and possibly lysine, if lepidopteran powders are to be used in chick rations. These profiles are consistent with findings on Lepidoptera by other investigators (Conconi and Bourges 1977, Wijayasinghe and Rajaguru 1977), particularly in regard to the sulfur-containing amino acids methionine and cysteine, which have appeared to be deficient by biochemical methods. These apparent deficiencies indicated by biochemical analysis were not substantiated, however, in the feeding trial that we conducted.

The chicks used in the bioassay fed readily on the experimental diets shown in Table 3. There were no significant differences in the average weight gain of chicks at 18 ($F = 0.57$; df = 25; $P < 0.001$) or at 21 ($F = 0.95$; df = 21; $P < 0.001$) days of age (Table 4), although chicks initially grew more rapidly on amino acid-supplemented *H. cecropia* diet. Chicks fed the experimental diets tended to eat less, and feed-to-gain ratios were as good or better than those obtained on the controls. Supplementing the diets with amino acids as shown in Table 4 had no significant effect on weight gains, indicating that the lepidopteran protein used in these tests was probably of higher quality than the amino acid profiles indicated. Mortality was confined to the control treatment, in which two birds died of unknown causes.

The results of this feeding trial indicate that the lepidopteran protein used is probably similar in its amino acid availability to that of the Mormon cricket and the house cricket, *Acheta domesticus* (L.), two insects on which we have accumulated considerably more data. The amino acid profiles of the lepidopterans were similar to those of the crickets, and broiler chick feeding trials comparing conventional corn/soybean diets with corn-ground Mormon cricket diets have shown no significant differences, either in final weights or feed/gain ratios (DeFoliart et al. 1982, Finke et al. 1985). The latter investigators suggested that the high level of choline in the Mormon cricket (4,900 mg/kg) may act as a methyl group donor in transmethylation reactions, thus reducing the need of methionine. They also found, using purified diets, that the lysine in ground crickets is readily available, and that methionine and arginine are co-limiting. Only when both amino acids were added was there a significant increase in final weights and a significant decrease in feed/gain ratios.

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