

Comparison of Diets for Mass-Rearing *Acheta domesticus* (Orthoptera: Gryllidae) as a Novelty Food, and Comparison of Food Conversion Efficiency with Values Reported for Livestock

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ABSTRACT As part of research on mass-rearing the cricket *Acheta domesticus* (L.) as a novelty (innovative) food, four cricket diets, two prepared in the laboratory and two commercial, were compared on the basis of cost per kilogram (wet weight) of eighth instars produced. Costs were influenced by dietary ingredients, mean cricket wet weight at time of harvest, and feed/gain ratios. For the laboratory-prepared diets, crickets grown on Patton's diet no. 16 or on NRC reference chick diet averaged 0.443 and 0.418 g at time of harvest, with feed/gain ratios of 0.923 and 0.949, respectively. Because of the cost of ingredients, however, the cost per kilogram of live crickets produced was only \$0.21 for the NRC chick diet compared with \$2.55 for Patton's no. 16; these costs exclude the cost of labor for mixing the diets. Performance of crickets on the laboratory-prepared diets was somewhat better than performance on the commercial diets. The food conversion efficiency of crickets at 30°C or higher was found to be higher than reported for broiler chicks and pigs and much higher than those reported for sheep and cattle.

KEY WORDS Insecta, *Acheta domesticus*, human food, diets

SEVERAL SPECIES OF crickets are used as food by non-European cultures, notable among which are *Brachytrupes portentosus* (Lichtenstein) throughout southern Asia and *Brachytrupes membranaceus* Drury throughout eastern Africa (DeFoliart 1989). Although crickets are not usually thought of as food for humans in the United States, the house cricket, *Acheta domesticus* (L.), is one of several insects recommended by Taylor & Carter (1976) for inclusion in their gourmet recipes. Nutritionally, the cricket has been shown to be a protein source of high quality in feeding trials with chicks (Nakagaki et al. 1987) and weanling rats (Finke et al. 1989). As a result of these attributes, we are investigating the mass production of *A. domesticus* as a novelty food (a new, unusual, or innovative food) for human use.

Our main objective in the work reported here was to determine which of several available cricket feeds could be used to produce crickets of harvestable age at the lowest possible cost. In our earlier rearing of crickets for use in animal feeding trials, we used Patton's diet no. 16 as the feed for crickets. Of 16 oligidic diets tested by Patton (1967), this diet produced the best overall cricket performance. The ingredients used to prepare the diet, however, make it quite expensive (\$2.76 per kg of feed) for use in mass rearing crickets for experimental animal feeding trials and far too expensive for use on a commercial scale. Preliminary cricket feeding trials with a formulation prepared accord-

ing to specifications of the National Research Council (NRC) reference chick diet (National Research Council 1977) gave good results and led to the cricket-feeding experiments reported here. In addition to Patton's diet no. 16 and the NRC chick diet, a commercial cricket feed and a commercial rabbit chow were included in the tests.

The results of our tests permit a comparison of feed costs in cricket production and also a comparison of the food conversion efficiency (ECI) of the cricket with those reported for conventional vertebrate livestock. Wet-weight ECIs ($ECI = [\text{weight gained}/\text{weight food ingested}] \times 100$ [Waldbauer 1968]) were recorded for two reasons. First, crickets are shipped alive to buyers, and recipes (Taylor & Carter 1976) are based on the use of freshly killed or frozen crickets. Second, feed/gain ratios of livestock are determined on a whole body, live-weight basis; thus cricket wet weights were needed for direct comparison of crickets and livestock sent to market. We have also attempted comparisons of both wet and dry weight ECIs when losses due to dressing percentage and carcass trim are included.

Materials and Methods

In all experiments except one, cricket feeders and housing materials were made of plastic. Waterers were glass vials filled with deionized water and plugged with dental rolls. Except in the ex-

Table 1. Proximate analyses, calculated metabolizable energy, and cost of experimental diets fed to crickets

Diet	% Crude protein	% Crude fat	% Ash	% Crude fiber	Metabolizable energy, kcal/kg	Cost, \$/kg
Patton's no. 16	30.5	5.2	5.1	2.8	3,156	2.76 ^a
NRC reference chick diet	22.3	5.5	4.4	4.9	3,118	0.22 ^a
Selph's cricket feed	17.0 ^b	3.5 ^b	—	4.0 ^c	3,000	1.21 ^d
Purina Rabbit Chow	14.0 ^b	2.0 ^b	10.0 ^c	20.0 ^c	2,180	0.38 ^e

^a Cost of ingredients only; cost of labor for mixing diets not included.

^b Label-guaranteed minimum.

^c Label-guaranteed maximum.

^d Purchased in 4.55-kg lots.

^e Purchased in 22.73-kg lots.

periment comparing performance on different diets, all crickets were fed the NRC reference chick diet described below. All diets were ground in a Wiley mill to a 20-mesh particle size, and all experiments were conducted under a 24 h daylight regimen. At the conclusion of experiments, crickets were killed by freezing and then weighed.

To harvest the maximum proportion of large, unwinged nymphs, it was necessary to determine the rate at which adult crickets appear in a cohort at a given temperature. An experiment was conducted in 19-liter aquaria at $35 \pm 2^\circ\text{C}$, using five replicates of 200 crickets each fed the NRC standard reference chick diet for 40 d. The proportion reaching the adult stage was tabulated at 3-d intervals following the first appearance of adults.

To determine ECIs of cricket cohorts fed the different experimental diets, newly hatched crickets were fed Patton's modified diet no. 16 for 3 d before transfer to vented plastic cages (8 by 18 by 4 cm). The experiment was conducted at $33 \pm 2^\circ\text{C}$. Fifteen replicates of 10 crickets per cage were fed one of four diets for 21 d; crickets were harvested at 24 d of age (for proximate analyses and calculated metabolizable energy of the diets, see Table 1). The diets are as follows:

Patton's modified diet no. 16. Contains 30 g soybean meal (41% protein), 25 g wheat middlings, 15 g dried skim milk, 10 g corn meal, 10 g dried brewer's yeast, and 10 g defatted liver powder. This diet was slightly modified in our test by the addition of 0.5 g cholesterol.

Purina Rabbit Chow (Purina Mills, St. Louis, Mo.). A pelleted commercially available maintenance diet for nonbreeding rabbits.

Selph's Cricket Feed (Selph's Cricket Ranch, Inc., Memphis, Tenn.). A commercially available cricket diet.

NRC reference chick diet. Ingredients are present in the following percentages: Ground yellow corn, 58.0; soybean meal, 35.0; corn oil, 3.0; calcium carbonate, 1.0; dicalcium phosphate, 2.0; iodized salt, 0.5; DL-methionine, 0.25; and choline chloride (50%), 0.15. The following ingredients are mg/kg diet: Manganese sulfate $\cdot 5\text{H}_2\text{O}$, 170.0; zinc sulfate $\cdot \text{H}_2\text{O}$, 110.0; ferric citrate $\cdot 5\text{H}_2\text{O}$, 500.0; copper sulfate $\cdot 5\text{H}_2\text{O}$, 16.0; sodium selenite, 0.2;

thiamine-HCl, 1.8; riboflavin, 3.6; calcium pantothenate, 10.0; niacin, 25; pyridoxine-HCl, 3.0; folic acid, 0.55; biotin, 0.15; vitamin B₁₂, 0.01; and vitamin K-1, 0.55. Vitamin A was added to the diet at a rate of 1,500 units/kg of diet, vitamin D₃ at 400 units/kg of diet, and vitamin E at 10 units/kg of diet. The 1,2 dihydro-6-ethoxy-2,2,4-trimethylquinoline (ethoxyquin) was omitted from the diet because Patton (1963) found that feeding medicated diets adversely affected cricket growth.

As it would be desirable to clear the gut in crickets intended for human consumption, wet weight was determined for crickets deprived of feed the last 24 h before harvest compared with crickets not so deprived. Both groups had ad lib access to water up to the moment of harvest. The dry weights of crickets in this experiment were also obtained. Each test group consisted of 10 replicates of 14 juvenile crickets (7 males, 7 females). The crickets were killed by freezing 4 d after the appearance of the first adult. The crickets were weighed, dried in a 60°C drying oven, then reweighed until there were no further changes in weight. Cricket legs are not usually ingested when nymphs are used as party snacks or in recipes; therefore, the proportion of whole-body weight represented by the legs was recorded in this experiment.

Differences between means were determined using Tukey's multiple range test for unequal sample sizes and the Student-Newman-Keuls revised LSD test (USDA 1977).

Results and Discussion

Our system for producing crickets as a potential novelty food is designed for harvest of eighth (final) instars to obtain crickets before they attain their wings. At $33\text{--}35 \pm 2^\circ\text{C}$, we have ordinarily harvested crickets at 28–30 d after the eggs hatch, at which time only a few have reached the adult stage. In the experiments conducted to gain more precise data on the temporal occurrence of adult crickets within a cohort, the mean interval to appearance of the first adults was 26.8 ± 0.44 d ($\bar{x} \pm \text{SE}$)(SD, 1.4). At 3 d after appearance of the first adults (or day 30 after eggs hatch), adults comprised $3.5 \pm 0.19\%$ of the cohort; at 33 d, $30.5 \pm 1.16\%$; at 36

Table 2. Weights ($\bar{x} \pm SE$) and feed/gain ratios of *A. domesticus* after 21 d on experimental diets (wet-weight basis)

Diet	Wt crickets, g \pm SE	Feed/gain	Protein gained/ protein fed	Feed cost/kg of crickets produced, \$
Patton's no. 16	0.443 \pm 0.009a	0.923 \pm 0.012a	0.745 \pm 0.009d	2.55
NRC reference chick diet	0.418 \pm 0.007ab	0.949 \pm 0.026a	0.999 \pm 0.026b	0.21
Purina Rabbit Chow	0.407 \pm 0.007b	1.651 \pm 0.030b	1.139 \pm 0.013a	0.63
Selph's cricket feed	0.406 \pm 0.010b	1.081 \pm 0.012a	0.908 \pm 0.015c	1.31

Means within the same column followed by different letters differ significantly ($P < 0.05$) (see text).

d, $53.1 \pm 3.04\%$; and at 39 d, $79.3 \pm 3.53\%$. On the basis of these data (and past experience), crickets used in the feeding trials with experimental diets were killed at 24 d after eggs hatched to preclude the appearance of any adults.

In the feeding trials with experimental diets, the modified Patton's diet no. 16, not unexpectedly, produced the largest crickets (mean wet weight 0.443 g) and the best feed: gain ratio (0.923) (Table 2). The diet is very high in protein and contains liver powder which is thought to contain a growth factor (Neville et al. 1961, Patton 1967). The size ($F = 4.29$; treatment $df = 3$, error $df = 56$; $P < 0.05$) and feed: gain ratio ($F = 253.8$; treatment $df = 3$, error $df = 56$; $P < 0.05$) of crickets fed Patton's diet were not significantly better, however, than those obtained with the NRC reference chick diet (mean wet weight 0.418 g; feed: gain ratio 0.949), and the feed: gain ratio on Patton's was not significantly better than that obtained on Selph's Cricket Feed (1.081). Considering the low protein, low metabolizable energy, and high fiber content of Purina Rabbit Chow, this diet performed remarkably well (Table 2). Because these nymphs were harvested at 24 d of age, they were slightly smaller than nymphs would be at normal harvest age. In our experience, the mean weight of cricket cohorts fed NRC diet to age 28–30 d has routinely been about 0.45 g.

In protein efficiency (based on label information for the commercial products) Purina Rabbit Chow ranked as best followed by the NRC diet, the Selph's Cricket Feed and Patton's no. 16 (Table 2). All differences were significant ($F = 21.6$; treatment $df = 3$, error $df = 56$; $P < 0.05$).

From the standpoint of feed costs per kilogram of live crickets produced, the NRC reference chick diet was clearly superior to Patton's no. 16, costing only \$0.21/kg (wet weight) compared with \$2.55/kg for the latter (Table 2). These costs are for the diet ingredients only and do not include labor; therefore, they cannot be compared directly with the prices of the commercial diets. With the equipment available to us, it requires about 2 h to weigh, grind, and mix 10 kg of diet. About half of this time is spent in grinding the materials in a Wiley mill. Thus, the labor increment averages about 12 min/kg of feed prepared.

Of the two commercial diets, from the standpoint of feed costs per kilogram of live crickets

produced, the Purina Rabbit Chow cost only \$0.63/kg (wet weight) compared with \$1.31/kg for Selph's Cricket Feed (Table 2). This apparent cost advantage is reduced somewhat, however, by the fact that Selph's is ready to feed as purchased, whereas Purina Rabbit Chow is formulated as pellets which must be ground to 20-mesh particle size before use. In comparatively large-scale cricket production, until there is a change in commercial availability of formulations, the decision whether to use hand-mixed or commercially available feed would depend on the individual situation relative to labor.

For commercially produced crickets sold live for fish bait, caged bird feed, or reptile feed, the current prices are about \$15/1000 with suggested retail prices of \geq \$3/100. At 2,000–2,200 crickets/kg, the prices are about \$30/kg and \$60/kg for crickets sold at wholesale and retail, respectively. From our feeding trial data, it is evident that the cost of feed ingredients represents a very small fraction of the current price of crickets sold commercially. If crickets were to become popular as a party snack, the profit potential for locally produced crickets as a small-farm specialty crop is obvious.

The whole-body composition (wet weight proximate analysis) of late eighth instars as found by Woodring et al. (1977) shows nymphs to be substantially higher in water content, generally similar in protein level, and substantially lower in fat than is the case in vertebrate livestock (whole body, but ingesta-free) at market age (Table 3). Although the crude protein level of fresh crickets is similar to that of vertebrate livestock, the quality, based on NPU (net protein utilization), PER (protein efficiency ratio), and chemical score in relation to amino acid content in egg protein is lower than that of protein from vertebrate animals and other high-quality protein sources such as whole hen's egg and casein (e.g., Dreyer & Wehmeyer 1982, Ozimek et al. 1985). Insect crude protein is of relatively low digestibility compared with these sources, apparently because some of the nitrogenous components are in the form of chitin in the integument, and chitinase is absent from monogastric animals. When the chitin is removed the protein quality improves. Ozimek et al. (1985) reported that removal of chitin following alkali extraction improved the true protein digestibility, PER, and NPU from 71.5%, 1.50, and 42.5, respectively, in whole

Table 3. Body composition of animals at market weight (vertebrates on an ingesta-free basis) and ECI of livestock and crickets in terms of live weight gain, dressing percentage, and carcass refuse

Species and references	% Water	% Protein	% Fat	% Wet wt ECI	% Dressing ^a	Carcass refuse ^b
Cricket nymph						
Woodring et al. 1977	68.4	15.0	10.3	—	—	—
This paper	74.2	—	—	92	100	20
Broiler chick						
Ensminger 1980 (market)	64.0	18.8	14.2	—	—	—
Meyer & Nelson 1963 (age 8 wk) ^c	—	28.6	4.9	35	68	—
Lovell 1979	—	—	—	48	72	32
Pig						
Ensminger 1980	50.0	13.0	34.4	—	—	—
Meyer & Nelson 1963 ^c	—	12.7	38.0	28	67	—
Whittemore & Elsley 1976	52.6	14.7	29.5	—	—	—
Lovell 1979	—	—	—	31	65	21
Sheep						
Ensminger 1980 (fat)	53.2	15.0	29.0	—	—	—
Meyer & Nelson 1963 ^c	—	15.2	25.2	18	54	—
Steer						
Ensminger 1980 (choice)	53.5	17.0	26.0	—	—	—
Meyer & Nelson 1963	—	18.2	21.1	16	60	—
Berg & Butterfield 1976	52.0	17.1	26.9	—	—	—
Lovell 1979	—	—	—	13	58	15

^a The marketable percentage of the animal after slaughter.

^b In poultry, bones only; in pork and beef, bones, trim fat, and tendons; in crickets, legs (17% of wet weight), crude fiber (<3.0%; although not removed, fiber is here considered as refuse because of its indigestibility).

^c Average for animals fed either a high-fiber or low-fiber diet.

dried honey bees (*Apis mellifera* L.) to 94.3%, 2.47, and 62, respectively, in the protein concentrate. The corresponding values for casein were 96.8%, 2.50, and 70, respectively. In addition, whole ground insects have been shown to be an excellent source of protein compared with most plant sources (e.g., Finke et al. 1989).

Our data and those of Meyer & Nelson (1963) can be used to compare the wet weight ECI of *A. domesticus* and young vertebrate livestock fed a similar dietary protein level (Table 3). Meyer & Nelson conducted feeding trials on both high- and low-fiber diets containing, respectively, 21.4 and 19.4% crude protein, 4.2% ether extract, 13.6 and 7.6% crude fiber, 3.7 and 1.7% lignin, 7.0 and 6.3% ash, and 4.87 and 4.85 kcal of gross energy/g (the ECIs in Table 3 are an average for these two diets). Ages of the animals at the beginning of the feeding trials and durations of the trials were: chicks 1 d, fed for 56 d; pigs 12 wk, fed for 90 d; sheep 5 mo, fed for 60 d, and; steers 8 mo, fed for 134 d. As shown in Table 3, the wet-weight ECI of *A. domesticus* in our trials (based on the average of the four diets in Table 2) was far higher than the efficiency found for any of the vertebrate species by Meyer & Nelson; i.e., more than twice as high as in chicks, ≈ 3 times higher than in pigs, 5 times higher than in sheep, and nearly 6 times higher than in cattle. Cricket efficiency in our trials was also much higher than efficiencies summarized from a number of sources for terrestrial livestock by Lovell (1979) (Table 3).

Meyer & Nelson chose their rations to study comparative utilization of the same proportion of feed-stuffs by the different species and recognized that the rations were not necessarily the most suitable for each species. In their tests, the pigs, sheep, and steers were all at market weight when the trials were terminated, whereas the chicks, although fed for 8 wk, weighed only about half as much as the market-ready broilers listed by Ensminger (1980) (Table 3), suggesting that neither of the diets fed by Meyer & Nelson were conducive to high food conversion efficiency in chicks. The efficiency of crickets, however, was still nearly twice as high as the much higher efficiency reported for broilers by Lovell (1979).

In comparing food conversion efficiency of crickets with vertebrate livestock, two additional factors must be considered to obtain a true conversion efficiency from animal feed to human food. These are dressing percentage and carcass refuse (Table 3). For each class of vertebrate livestock, these two factors together reduce the edible portion of the dressed carcass to $\approx 50\%$ of whole-body weight. A comparable, but reduced, loss occurs in the nymphal cricket carcass when legs are discarded and because the chitinous integument, although not usually removed, is indigestible by simple-stomached animals. The crude fiber (integument) of the live cricket comprises <3% of its body weight, however, based on a dry weight crude fiber content of 7.0% reported by Nakagaki et al. (1987), and the legs comprise $\approx 17\%$ of total

Table 4. Dry matter percentage of eighth instars and "carcass loss" represented by removal of legs

	Crickets starved last 24 h		Crickets not starved	
	\bar{x}	SE	\bar{x}	SE
Whole Body				
Wet wt, g	0.456	0.006	0.463	0.008
Dry wt, g	0.116	0.002	0.121	0.003
% Dry matter	25.4	0.164	26.2	0.21
Legs only				
Wet wt, g	0.079	0.001	0.077	0.001
As % of whole body	17.3	0.17	16.6	0.24
Dry wt, g	0.021	0.004	0.020	0.004
As % of whole body	18.2	0.34	16.8	0.28

body weight (Table 4). In Table 3, we have assigned both crude fiber and legs to the carcass refuse category as legs would be present in crickets marketed alive. If marketed fresh-frozen or freeze-dried, they might or might not have the legs removed.

The whole-body ECI margin in favor of crickets is reduced when calculated on a dry weight basis because of the higher water content of crickets (Table 5D). The calculations in Table 5 are based on the averages of the values given in Table 3 for whole-body live weight, whole-body water content, dressing percentage, and carcass refuse; thus, they represent rough approximations only. The dry weight of cricket nymphs was found to be $\approx 26\%$ of fresh weight in our test, $\approx 25.4\%$ in crickets denied access to feed the last 24 h before harvest and $\approx 26.2\%$ in crickets not deprived of access (Table 4). These dry-weight ratios are somewhat lower than the 31.6% dry weight found by Woodring et al. (1977) on late eighth instars, suggesting that many of our crickets were in the early eighth instar at time of harvest. Their data were averages for the final five days, days 4–8, of the eighth instar; Woodring et al. (1977, 1979) have shown that water content in the eighth instar nymph declines from a first-day peak of 74–75.9% to a steady 68% by

the third or fourth day after ecdysis. Food consumption virtually ceases during the last 2–3 d of both the seventh and eighth instars, but water consumption continues and there is no loss in either wet or dry weight (Woodring et al. 1977, Roe et al. 1980). Woodring et al. (1979) reported an ECI, at 30°C, of 29% for the eighth instar female *A. domesticus* on a dry-weight basis. This ECI obtained on the final instar can probably be considered as conservatively representative for the entire nymphal period, as a high proportion of growth in most insects takes place in the final two instars and ECIs tend to be as high or higher in the earlier instars (Waldbauer 1968).

When losses due to dressing percentage and carcass refuse are accounted for, the adjusted dry weight ECI of crickets is still more than twice as high as those of broiler chicks and pigs, >4 times higher than sheep, and nearly 6 times higher than steers (Table 5, E). One negative aspect is that the high cricket ECIs discussed here are observed only at temperatures of about 30°C or higher. Roe et al. (1980) found (last-instar female) dry-weight ECIs of 30 and 32 at temperatures of 30 and 35°C, respectively, but an ECI of only 20 at a temperature of 25°C.

Finally, in considering feed utilization efficiency in the broad sense, crickets have high fecundity, especially in comparison with that of ruminant herbivores and pigs. Female *A. domesticus* lay an average of 1,200–1,500 eggs over a period of 3–4 wk after reaching the adult stage (Patton 1978). Compared with this, in beef production about four animals exist in the breeding herd per market animal produced (Long et al. 1975, Trenkle & Willham 1977). The advantage in fecundity is less when insects are compared with poultry.

Our data have permitted a comparison of efficiency between an insect omnivore, *A. domesticus*, and conventional livestock species when both are fed the high-quality diets used in bringing the latter to market condition. Despite the difficulties and lack of precise accuracy in such comparisons be-

Table 5. Feed conversion efficiency (ECI) of crickets and vertebrate livestock, calculated to include losses resulting from carcass dressing percentage and carcass refuse^a

Factors	Cricket nymph	Broiler chick	Pig	Lamb	Steer
A. Whole-body live weight ECI (%)	92	48	29.5	18	14.5
B. A minus reciprocal of dressing percentage ^b	92 (0)	33.6 (30)	19.5 (34)	9.7 (46)	8.6 (41)
C. B minus carcass trim (=adjusted wet wt ECI) ^b	73.6 (20)	22.8 (32)	15.4 (21)	<9.7 ^c	7.3 (15)
D. Whole-body dry wt ECI (%) ^d	26.4 (71.3)	17.3 (64)	14.4 (51.3)	8.4 (53.2)	6.8 (52.8)
E. C minus water (=adjusted dry wt ECI) ^e	21.1 (71.3)	9.9 (56.6) ^f	8.5 (44.7) ^f	4.8 (50.3) ^f	3.6 (51.3) ^f

^a Values in this table relating to whole body live weight ECI, dressing percentage, carcass trim, and (except as noted) water content are averages of the corresponding values given in Table 3. An exception to this is the whole-body live weight ECI of 48% for the broiler chick (see text for explanation).

^b Percentage loss from values given in the preceding row shown in parentheses.

^c No data available.

^d Percentage loss from values given in Row A shown in parentheses.

^e Percentage loss from values given in Row C shown in parentheses.

^f Average moisture in cuts classed as "lean and fat." Source: Nutritive Value of Foods, 1970, Consumer and Food Economics Research Division. Meat from which the fat has been trimmed off in the kitchen or on the plate contains more water than shown here for meat classed as "lean and fat."

tween animals having widely differing dietary and husbandry requirements, it is apparent that *A. domesticus* is relatively efficient in its food resource utilization compared with conventional terrestrial livestock. The food conversion efficiency of animals is one of the important factors that must be considered in choosing environmentally sound food alternatives for the future. Edible insects are among the alternatives (DeFoliart 1989). The ECI of insects varies widely depending on species and type of food consumed (e.g., forbs, grasses, woody plant herbage, wood, organic wastes, etc.) (Slansky & Rodriguez 1987) and, considering that insects are traditional foods in many cultures, comparisons between insects and vertebrate species are needed in a variety of different resource utilization situations.

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