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Soldier fly, *Hermetia illucens* L., larvae as feed for channel catfish, *Ictalurus punctatus* (Rafinesque), and blue tilapia, *Oreochromis aureus* (Steindachner)

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Abstract. Three feeding trials, involving pre-pupal larvae of soldier fly, *Hermetia illucens* L., grown on poultry manure, were conducted to assess: (1) channel catfish, *Ictalurus punctatus* (Rafinesque), response to substitution of dried meal larvae for the fish meal component of the catfish diet and (2) if feeding 100% whole or chopped larvae to channel catfish or blue tilapia, *Oreochromis aureus* (Steindachner), will support normal growth comparable to those fed a commercial diet. Effects on fish quality were also evaluated. Replacement of 10% fish meal with 10% soldier fly larvae resulted in slower growth over a 15-week period for subadult channel catfish grown in cages (trial 1). However, the replacement did not reduce growth rate significantly when channel catfish were grown in culture tanks at a slower growth rate (trial 2). Feeding 100% larvae did not provide sufficient dry matter or protein intake for good growth for either species grown in tanks (trials 2 and 3). Chopping of the larvae improved weight gain and efficiency of the utilization.

Introduction

The concept of producing feed from agricultural by-products and animal excrement has been investigated. Frequent feed price increases and the challenge of economical fish farming prompted research for less expensive feed sources especially with regard to protein. Edwards (1980) proposed that fish, grown on recycled organic wastes, may be the cheapest animal-food products. Here, we investigated the use of soldier fly larvae, *Hermetia illucens* L., as an alternate animal protein and fat source and as a fish meal substitute for rearing channel catfish, *Ictalurus punctatus* (Rafinesque), and blue tilapia, *Oreochromis aureus* (Steindachner).

The soldier fly is found in moist tropical and subtropical regions throughout the world (James 1935) and is common in the southern United States. The life cycle of this insect is 4–5 weeks under good conditions but can be lengthened to several months by cool temperatures or food shortage. The larvae grow in a wide range of decaying organic matter ranging from moist grain to animal manures. Waste recycling by soldier fly larvae can satisfactorily be used in diets of young chicks (Hale 1973) and young pigs (Newton, Booran, Barker & Hale 1977).

A review of literature by Bondari & Sheppard (1981) indicated that insects in various developmental stages have received considerable attention as alternate sources of protein. Aerial insects have been attracted by light to be used as supplemental food for channel catfish (Merkowsky, Handcock & Newton 1977) and bluegill sunfish, *Lepomis macrochirus*

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Rafinesque (Heidinger 1971). Bondari & Sheppard (1981) demonstrated that blue tilapia, *Tilapia aurea* (Steindachner), will grow satisfactorily over a 10-week period when fed diets containing 50, 75 and 100% soldier fly larvae. The study also included channel catfish which did not perform well in polyculture tanks with tilapia. The present study was conducted to determine: (1) if soldier fly larvae could replace the fish meal in a catfish diet with no adverse effects on either growth or fish quality and (2) whether 100% whole or chopped soldier fly larvae contain sufficient nutrients to support normal growth of channel catfish or blue tilapia.

Materials and methods

Soldier fly larvae used in this study were either manually collected as young larvae from caged laying hen manure in a commercial operation or self-collected at an experimental caged layer house as mature larvae (pre-pupae). Mature larvae were larger, and higher in fat content. Production estimates indicate that one to two metric tons of larvae/moth can be produced from a 20000-chicken layer house during May to September (Bondari & Sheppard 1981). A simple modification of present manure collection practices allows for continuous self-collection of mature larvae. Large mature larvae are collected as they seek to leave the moist manure to find a dry pupation site.

Three feeding trials, with both cage- (trial 1) and tank- (trial 2) reared channel catfish and tank-reared blue tilapia (trial 3) were conducted to address the stated objectives. In trials 1 and 2, formulated diets contained basal plus 10% fish meal and basal plus 10% dried, ground soldier fly larvae (Table 1). Both 10% fish meal (30% crude protein and 8·1% fat) and 10% larvae (24% crude protein and 10·8% fat) diets were sinking pelleted diets about equal in metabolizable energy content (2·4 and 2·5 Kcal/g respectively). The fish meal contained 72% protein, 8·4% fat and 1·0% fibre. Dried soldier fly larvae contained considerably less protein (38–40%), more fat (18–28%), and more fibre (5–7%). Both fish meal and larvae diets were prepared by a commercial feed manufacturing company. The fish meal diet was a product of this company sold to fish growers. A commercial floating diet containing 37·5% crude protein, 8·0 fat and 5·0 crude fibre was also used in trials 1 and 2 as a standard diet to be compared with the two formulated sinking pellets. The main ingredients of the commerical diet were ground yellow corn, fish meal, soybean meal, corn gluten, meat and bone meal, dried whey, soybean oil, dehydrated alfalfa meal, and animal fat. Percentages have not been released by the manufacturing company. The commerical diet used as a standard diet for blue tilapia (trial 3) was a sinking trout chow containing 37·5% crude protein and a minimum 5% crude fibre and 8% fat.

Trial 1 (cage culture)

Trial 1 included 15 floating cages (86 × 89 × 122 cm) placed in a 2-ha reservoir. Water depth in each cage was about 100 cm, and each cage contained 25 males (average weight of 197 g) and 25 females (average weight of 186 g). Five cages of channel catfish were randomly assigned to each of the three diets (10% fish meal, 10% larvae, or commercial) for a total of 250 fish/diet. Fish were fed approximately 3% of body weight in one (1–7 weeks) or two (8–15

Table 1. Percentage composition of formulated diets used in trials 1 and 2

Ingredient	Basal + 10% fish meal	Basal + 10% larvae
Fish meal	10·0	–
Dried larvae	–	10·0
Basal		
Fat	6·0	6·0
Poultry by-product	9·0	9·0
Soybean meal	10·0	10·0
DDG/S	8·0	8·0
Rice mill feed	30·0	30·0
Wheat midds	8·0	8·0
Alfalfa	5·0	5·0
Gluten feed	10·0	10·0
Supplement[a]	4·0	4·0
Total	100·0	100·0
Chemical analysis		
Metabolizable		
Energy (Kcal/g)	2·4	2·5
Crude protein (%)	30·0	24·0
Fat (%)	8·1	10·8

[a] Supplied the following per kg of diet: calcium, 9400 mg; phosphorus, 1512 mg; manganese, 56 mg; zinc, 56 mg; iron, 22·4 mg; copper, 5·6 mg; iodine, 1·68 mg; cobalt, 0·28; methionine HA, 1120 mg; Terramycin, 24 mg; pellet binder, 19·8 g; vitamin A, 33 920 USP; vitamin D_3, 6784 IC; vitamin E, 30 I; vitamin B_{12} 0·04 mg; riboflavin, 24 mg; calcium d-pantothenate, 43·6 mg; niacin, 145 mg; menadione, 47 mg; folic acid, 3·6 mg; thiamin, 16 mg; pyridoxine, 16 mg; ascorbic acid, 24 USP; biotin, 0·56 mg; choline, 560 mg.

weeks) daily feedings. This trial began on 21 July 1980 and ended on 5 November 1980. A random sample of five male and five female catfish was selected from each cage at the end of the experiment for taste evaluation.

Trial 2 (tank culture)

In addition to the three diets used in trial 1, channel catfish were fed a diet containing 100% soldier fly larvae in trial 2. In this trial 16 tanks (30·5 × 122 × 35·5 cm) each containing 20 male (average weight of 130 g) and 20 female (average weight of 109 g) catfish were used. Initially, four tanks of fish were assigned at random to each diet for a total of 160 fish/diet. The fish were fed to satiation for 15 min, three times daily. Aerating nozzles supplied well water heated to 27°C at an approximate rate of 4 l/min for each tank during the first 13 weeks of the experiment. All tanks were supplied with aerated well water at 22°C during the remaining 7 weeks.

Channel catfish fed 100% soldier fly larvae as a sole diet were fed whole larvae during the first 7 weeks of the experimental period. During weeks 8–13, two of the four tanks in the larvae diet group received chopped larvae as described by Bondari & Sheppard (1981). A manually operated food chopper was used to chop the larvae. At the end of the 13-week period, all fish were sexed, individually weighed and measured for total length. Individual weight gain, feed consumption (amounts offered) and feed efficiency (feed:gain ratio) were also determined. A taste test was also conducted as in trial 1.

Thirteen weeks after the experiment began, all catfish from two of the four tanks in each diet group were switched to the commerical floating diet for a 7-week period. Diets of the fish in the remaining two tanks during this period were the same as the previous 13 weeks. Carcass information and taste panel data were also obtained at the end of this 7-week period. Total duration of the tank trial for channel catfish was 20 weeks.

Trial 3 (tank culture)

This trial involved three diets (commercial, 100% chopped and 100% whole larvae) fed to blue tilapia. Three tanks of 30 fish each (average body weight of 32 g and total length of 125 mm) were randomly assigned to each of the three diets. An aerating nozzle supplied a constant flow of 22°C well water at the rate of 3·8 l/min for each tank (30 cm width × 122 cm length × 51 cm height). Water constantly exited through a standpipe so that the water turnover was once every 34 min/tank. Water depth was 36 cm in each tank; therefore, each tank contained 130 l of water. The fish from all three diet groups were fed all they would consume in 15 min, three times daily for a period of 20 weeks.

All fish in this and other trials were anaesthetized with tricaine methanesulphonate (MS-222) at the recommended concentration level and were individually weighed and measured for total length at the beginning and after 10 and 20 weeks. Feed consumption, feed conversion and mortality rate were also determined for each tank or cage. Feed consumption and feed conversion values in all three trials are on an 'as fed basis' since feed wastage could not be determined accurately.

Statistical analysis

Diet, sex and diet X sex effects were evaluated by least square analysis of variance (SAS Institute Inc. 1982) with cages (trial 1) or tanks (trials 2 and 3) used as replicates. Residual mean square was used to test the significance of each effect. Diet effect was also tested for each sex independently. Where appropriate, least squares mean comparisons were performed using the same statistical package.

Results and discussion

(1) Channel catfish (trials 1 and 2)

Average weekly gains (Table 2) indicated that channel catfish fed the commercial diet, whether in tanks or cages, gained consistently more ($P < 0{\cdot}05$) weight than those fed the 10% fish meal or 10% larvae diet. When the two sexes were combined, the overall weekly gains of channel catfish fed the 10% fish meal diet for 15 weeks in cages (trial 1) and 13 weeks in tanks (trial 2) were about 40 and 52% less ($P < 0{\cdot}05$) than those fed the commercial diet respectively. The respective values for the 10% larvae diet were 60 and 58%. Overall feed conversion values (Table 3) showed that the commercial diet was the most efficiently utilized ($P < 0{\cdot}05$) diet in both trials. Commercial and formulated diets (10% fish meal and 10%

Table 2. Average weekly weight gain (g) during selected growth intervals for channel catfish fed different diets in cages and tanks

	1–7 weeks		7–15[e] weeks		1–15[e] weeks	
Diet	Male	Female	Male	Female	Male	Female
Trial 1 (cage culture)						
Basal + 10% fish	12·7[b]	11·0[ab]	19·4[b]	17·0[b]	16·3[b]	14·2[b]
Basal + 10% larvae	10·0[b]	6·7[b]	12·1[c]	11·3[c]	11·1[c]	9·1[c]
Commercial	23·3[a]	15·9[a]	32·5[a]	28·1[a]	28·2[a]	22·4[a]
Trial 2 (tank culture)						
Basal + 10% fish	12·4[b]	6·4[b]	7·7[b]	8·8[b]	10·2[b]	7·5[b]
Basal + 10% larvae	11·7[b]	7·7[b]	5·8[bc]	5·7[c]	9·0[b]	6·8[b]
Commercial	24·3[a]	17·1[a]	18·8[a]	12·3[a]	21·8[a]	14·9[a]
100% larvae	5·4[c]	3·6[c]	2·3[c]	1·5[d]	4·0[c]	2·6[c]

[a,b,c,d] Means for each trial, within the same column, bearing different superscripts differ ($P < 0{\cdot}05$).
[e] The test period was 13 weeks for trial 2 (tank culture).

larvae) differed in both composition and processing method. Per cent protein also varied among diets and was expected to influence growth response in this study. The amino acid composition of the proteins was not determined. One reason for using the commercial diet was to use a standard diet, previously fed to channel catfish in our laboratory with known effects on growth and survival (Bondari 1984).

In general, there were no significant differences between average weight gain, feed consumption or feed efficiency of tank-grown channel catfish (trial 2) fed 10% larvae and those fed 10% fish diets at the end of 13 weeks (Tables 2 and 3). The cage-grown catfish had similar growth when fed the 10% fish or 10% larvae diet during the first 7-week period of trial 1. Growth of fish fed the 10% larvae diet was significantly less during the last 8-week period of

Table 3. Number of fish (*n*), average weekly feed consumption (as fed basis) in grams (FC), feed efficiency (FE), and mortality rate (%) for cage- and tank-cultured channel catfish fed different diets

	1–7 weeks			7–15[f] weeks			1–15[f] weeks		
Diet	*n*[d]	FC	FE	*n*	FC	FE	Mortality	FC	FE
Trial 1 (cage culture)									
Basal + 10% fish	244	46·7[a]	3·99[a]	242	58·4[b]	3·19[b]	3·2[a]	53·1[b]	3·49[b]
Basal + 10% larvae	246	43·4[a]	5·05[a]	242	57·0[b]	4·96[a]	4·0[a]	51·1[b]	5·04[a]
Commercial	230	45·1[a]	2·29[b]	230	73·7[a]	2·43[b]	8·0[a]	60·2[a]	2·38[c]
Trial 2 (tank culture)									
Basal + 10% fish	158	19·1[bc]	2·01[b]	155	11·8[b]	1·45[b]	3·1[a]	15·7[b]	1·77[b]
Basal + 10% larvae	158	18·1[c]	1·88[b]	157	10·7[b]	1·83[b]	1·9[a]	14·7[b]	1·88[b]
Commercial	158	20·4[ab]	0·99[c]	154	14·3[b]	0·89[c]	3·7[a]	17·6[b]	0·95[c]
100% larvae[e]	158	21·6[a]	4·78[a]	157	32·9[a]	16·46[a]	1·9[a]	26·8[a]	7·89[a]
		(4·2)	(0·90)		(6·3)	(3·16)		(5·2)	(1·52)

[a,b,c] Means for each trial, within the same column, bearing different superscripts differ ($P < 0{\cdot}05$).
[d] Initial number of fish was 250 per diet group in trial 1 and 160 in trial 2.
[e] Values in parenthesis were derived from a dry matter content of the larvae diet.
[f] The test period was 13 weeks for trial 2 (tank culture).

trial 1 and after 15 weeks than those fed the 10% fish meal diet (Table 2). Feed consumption by cage-grown catfish (trial 1) did not differ between fish fed 10% fish meal and 10% larvae diets throughout the 15-week experimental period (Table 3). Both male and female fish fed the 10% fish meal diet gained more ($P < 0{\cdot}05$) weight from 7 to 15 weeks (50% more for females and 60% more for males) and were 36% more efficient ($P < 0{\cdot}05$) in feed efficiency during this period than those fed 10% larvae diet (Tables 2 and 3).

Channel catfish fed 100% soldier fly larvae gained less ($P < 0{\cdot}05$) weight (Table 2, trial 2), consumed more ($P < 0{\cdot}05$) per week, and were the least ($P < 0{\cdot}05$) efficient in feed utilization (Table 3, Trial 2) when compared to the other diet groups on an as fed basis. Bondari & Sheppard (1981) determined that a ratio of 5·2 g of larvae to 1 g of commercial feed should be used to equalize the dry matter content of the two diets. Dry matter corrected feed efficiency values for the three periods (Table 3) were 0·90, 3·16 and 1·52 respectively, which are within the range of values obtained for other diets. The overall weekly feed consumption of 26·8 g (Table 3, trial 2) will then reduce to 5·2 g which is about one-third of the feed intake for other diets. The higher feed consumption rate of the fish fed the 100% larvae diet (Table 3, trial 2) as compared to the other three diets indicated that channel catfish were able to adapt somewhat to a high moisture diet while maintaining good feed conversion on a dry matter basis (1·52). It appears that depressed fish growth for this diet group may have been caused by an insufficient quantity of dry matter intake more than deficiencies in the the nutritional value of the 100% larvae meal. Mortality rate (Table 3) was low in both trials and was not diet related.

Body weight, total length, and carcass composition of catfish fed 10% fish and 10% larvae diets in tanks (trial 2), were similar after 13 weeks but both male and female catfish fed the 10% fish meal diet were significantly heavier and longer ($P < 0{\cdot}05$) than those fed the 10% larvae diet for 15 weeks in cages (Table 4). The cage-grown catfish (trial 1) in these two diet groups were also substantially heavier and longer than those grown in tanks (Table 4) and gained twice as much weight per week as did the tank-grown catfish (trial 2) during the second period (Table 2). Also, there were other differences between the two culturing systems including water temperature, feeding method and feeding frequency. The tank-culture trial was further continued to determine if the dietary response is size dependent and whether compensatory growth is observed after a period of growth retardation.

Sexual comparisons

Male catfish, fed a 100% larvae diet in tanks (trial 2), were significantly ($P < 0{\cdot}05$) lighter in body weight, absolute carcass and head weight and were shorter ($P < 0{\cdot}05$) in total length than those from the other three diet groups (Table 4). However, female catfish fed 100% larvae diet were statistically similar to females from 10% fish and 10% larvae diet groups in both weight and length averages. Relative carcass and head weights (expressed as percentages of body weight) of the female catfish from the 100% larvae fed group were similar to those of the 10% fish meal group. However, the males fed 100% larvae were statistically similar to the 10% fish meal fed males in per cent carcass weight but possessed significantly ($P < 0{\cdot}05$) larger heads relative to their body size (Table 4). Male and female catfish fed the commercial diet were superior ($P < 0{\cdot}05$) to the other three diet groups in body weight, total length, absolute and relative carcass weight and absolute head weight in both trials.

Table 4. Body weight (Wt), total length (TL), and carcass characteristics of cage-cultured (after 15 weeks) and tank-cultured (after 13 weeks) channel catfish determined from a random sample of five males and five females per cage or tank

	Wt (g)		TL (mm)		Carcass wt (g)		% Carcass		Head wt (g)		% Head	
Diet	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Trial 1 (cage culture)												
Basal + 10% fish	459^{b}	392^{b}	387^{b}	368^{b}	259^{b}	224^{b}	56·4^{b}	57·2^{b}	125^{b}	99^{b}	27·3^{b}	25·4^{a}
Basal + 10% larvae	382^{c}	320^{c}	375^{b}	357^{c}	208^{c}	176^{c}	54·3^{c}	55·0^{c}	112^{b}	83^{c}	29·3^{a}	26·0^{a}
Commercial	660^{a}	542^{a}	404^{a}	382^{a}	388^{a}	329^{a}	58·5^{a}	61·0^{a}	161^{a}	123^{a}	24·5^{c}	23·2^{b}
Cv (%)	27·6	26·3	7·6	6·6	29·1	26·5	5·2	6·6	28·2	21·5	7·8	11·1
Trial 2 (tank culture)												
Basal + 10% fish	312^{b}	222^{b}	332^{b}	306^{b}	177^{b}	128^{b}	56·5^{b}	57·3^{bc}	86^{b}	59^{b}	27·6^{b}	27·1^{a}
Basal + 10% larvae	292^{b}	200^{b}	336^{b}	301^{b}	163^{b}	113^{b}	55·8^{b}	56·3^{c}	84^{b}	55^{b}	38·9^{ab}	27·9^{a}
Commercial	530^{a}	323^{a}	387^{a}	333^{a}	315^{a}	194^{a}	59·3^{a}	60·1^{a}	140^{a}	82^{a}	26·6^{b}	25·7^{b}
100% larvae	190^{c}	183^{b}	299^{c}	299^{b}	107^{c}	107^{b}	56·8^{b}	58·1^{b}	56^{c}	52^{b}	29·8^{a}	28·2^{a}
Cv (%)	31·3	34·6	9·8	10·3	32·9	36·2	2·9	3·0	30·3	31·1	6·0	6·6

^{a,b,c} Means for each trial, within the same column, bearing different superscripts differ ($P < 0·05$).

These results indicated a differential sex response to different diets and that the use of different expressions of the same trait (e.g. carcass weight and per cent carcass weight) could lead to different conclusions (Table 4). Per cent carcass values were associated with considerably smaller coefficients of variation than absolute carcass values (Table 4) and should therefore be given more attention. Relative variability in body weight and carcass weight, determined by coefficient of variation (Cv), were similar in trials 1 and 2 and were three to four times greater than Cv per cent for total length.

Compensatory growth

When half of the tank fish from each of the 10% fish, 10% larvae and 100% larvae diet groups were switched to the commercial floating diet from the 13th to 20th week and the other half continued to receive the same diet as the previous 13 weeks, significant improvement in rate of weekly gain and feed utilization was observed (Table 5). Tank-grown channel catfish fed 10% fish and 10% larvae diets were similar in body weight after 13 weeks and remained similar in body weight, weekly gain, feed consumption and feed efficiency after 20 weeks (Table 5). Male and female catfish fed the commercial diet for 20 weeks had greater weight gain during the 13–20-week period and utilized feed more efficiently than those fed 10% fish, 10% larvae and 100% larvae diets for 20 weeks. Catfish, continuously fed 100% larvae diet for 20 weeks, gained less weight ($P < 0{\cdot}05$) from the 13th to 20th week, consumed more feed on a weekly basis, and were less efficient in feed utilization when compared with the other three diet groups (Table 5). When the average weekly gain of males and females were combined, the catfish fed 10% fish, 10% larvae and 100% larvae diets for 20 weeks gained only 43, 25 and 14% respectively of their counterparts switched to commercial diet during

Table 5. Body weight (g) after 13 and 20 weeks on test and 13–20-wk weight gain (g), feed consumption (FC), and feed efficiency (FE) of channel catfish fed basal + 10% fish meal (10% fish), basal + 10% larvae (10% lar), commercial (Com), and soldier fly larvae (100% lar) diets (trial 2)

Diet combination		13-wk weight		20-wk weight		13–20 wk gain		FC	
1–13 wks	13–20 wks	Male	Female	Male	Female	Male	Female	(g)	FE
10% fish	10% fish	265[b]	206[b]	306[d]	257[cd]	7·0[c]	8·6[cd]	22·1[b]	2·80[b]
10% fish	Com	–	–	427[bc]	309[bc]	22·5[a]	13·4[bc]	20·4[b]	1·12[c]
%[f]				(72)	(83)	(31)	(64)	(108)	(250)
10% lar	10% lar	250[b]	196[b]	333[d]	217[d]	7·6[c]	5·4[de]	18·1[b]	2·83[b]
10% lar	Com	–	–	475[ab]	363[ab]	28·8[a]	21·6[a]	22·3[b]	0·88[c]
%[f]				(70)	(60)	(26)	(25)	(81)	(322)
100% lar[h]	100% lar	178[c]	141[c]	202[e]	152[e]	4·5[c]	1·9[e]	37·0[a]	11·93[a]
100% lar	Com	–	–	365[cd]	265[cd]	25·4[a]	17·1[ab]	21·8[b]	1·01[c]
%[f]				(55)	(57)	(18)	(11)	(170)	(1181)
Com	Com	412[a]	305[a]	522[a]	383[a]	15·7[b]	11·1[c]	22·3[b]	1·64[c]

[a,b,c,d,e] Means, within the same column, bearing different superscripts differ ($P < 0{\cdot}05$).
[f] Means of each diet expressed as percentages of the same diet when switch to commercial diet was made from 13 to 20 weeks.
[h] The feed consumption and feed efficiency of 100% larvae diet adjusted for moisture content were 7·1 g and 2·30 respectively.

weeks 13–20. Such an increased growth following a period of growth retardation is known as compensatory growth.

Since the change of feed did not significantly change the weekly rate of feed intake (except for the larvae group), the increased rate of growth of fish switched to the commercial diet observed in this period (Table 5) is an indication of deficiencies in the 10% fish, 10% larvae and 100% larvae diets. The strongest compensatory growth was observed for the catfish fed 100% larvae where feeding of the commercial diet increased the weekly gain of the sexes combined by about sevenfold. Although the catfish fed 100% larvae increased their consumption significantly over the other diet groups (Table 5), the insufficient dry matter intake (and possibly, protein intake) apparently caused a severe growth retardation. When the feed consumption for this group is adjusted for the moisture content according to Bondari & Sheppard (1981), the feed efficiency of 11·93 for this group (Table 5) becomes 2·30 which is lower than the values obtained for fish on either 10% fish (2·80) or 10% larvae (2·83) diets.

(2) Blue tilapia (trial 3)

After 10 weeks, the fish fed chopped and whole larvae were 58–66% as heavy and 88–89% as long as those fed the commercial diet (Table 6). Corresponding values were 38–50% for body weight and 79–81% for total length after 20 weeks which show further decreases than observed after 10 weeks. The fish fed chopped and whole larvae did not differ significantly in body weight or total length after 10 weeks but were significantly lighter and shorter than those fed the commercial diet. However, after 20 weeks, fish from the three diet groups differed significantly in body weight and condition factor. Tilapia fed chopped larvae were heavier (52·2 *vs* 40·3 g) and had a greater ($P < 0{\cdot}05$) condition factor (1·73 *vs* 1·49) than those fed whole larvae.

Weight gain and length increase of the larvae-fed fish, expressed as percentages of those fed commercial diet, progressively decreased throughout the 20-week test (Table 6). Percentages were 36 and 22 for the weight gain of fish fed chopped and whole larvae respectively during the first 10-week period and were decreased to 20 and 2 during the second 10-week period. Corresponding values for length increase of blue tilapia were 40 and 37% for the first 10-week period and were decreased to 15 and 0% during the second 10-week period (Table 6). Overall 20-week percentages were 28 and 12 for weight gain and 30 and 23 for length growth of fish fed chopped and whole larvae, respectively.

Whole vs *chopped larvae*

One purpose in this study was to compare the performance between channel catfish or blue tilapia fed 100% chopped or 100% whole larvae. Results indicated that catfish fed whole larvae gained 76·7% of the weight of those fed chopped larvae from 7 to 20 weeks (Table 7). Corresponding value for blue tilapia was 41·7% (Table 6). However, feed consumption values were higher for the chopped larvae fed group for both fish species. As a result, chopped larvae were utilized less efficiently than whole larvae by channel catfish (Table 7). However, blue tilapia utilized chopped larvae 28% more efficiently than whole larvae (Table 6). We observed greater larvae waste in the chopped larvae fed tanks than in the whole larvae fed tanks in both trials.

Table 6. Growth, feed consumption, feed conversion, and survival of blue tilapia fed commercial and soldier fly larvae diets (trial 3)

Item	Commercial diet		Chopped larvae		Whole larvae	
	Mean	%[d]	Mean	%[d]	Mean	%[d]
After 10 weeks[e]						
Body weight (g)	68·3[a]	100	45·0[b]	66	39·7[b]	58
Total length (mm)	153·7[a]	100	136·3[b]	89	135·5[b]	88
First 10-week period						
Weight gain (g)	36·5[a]	100	13·2[b]	36	7·9[c]	22
Length growth (mm)	28·9[a]	100	11·5[b]	40	10·7[b]	37
Feed consumption (g)	83·7[b]	100	110·9[a]	132	77·8[b]	93
Feed conversion	2·29[b]	100	8·40[a]	367	9·84[a]	430
Mortality (%)	1·1[a]	100	6·7[b]	609	5·5[b]	500
After 20 weeks						
Body weight (g)	105·2[a]	100	52·2[b]	50	40·3[c]	38
Total length (mm)	171·9[a]	100	139·0[b]	81	135·5[b]	79
Condition factor[f]	1·80[a]	100	1·73[b]	96	1·49[c]	83
Second 10-week period						
Weight gain (g)	36·9[a]	100	7·2[b]	20	0·6[c]	2
Length growth (mm)	18·2[a]	100	2·7[b]	15	0·0[c]	0
Feed consumption (g)	97·7[b]	100	131·5[a]	135	51·2[c]	52
Feed conversion	2·65[c]	100	22·47[b]	848	56·23[a]	2122
Mortality (%)	1·1[a]	100	2·3[a]	209	2·4[a]	218
Overall 20-week period						
Weight gain (g)	73·4[a]	100	20·4[b]	28	8·5[c]	12
Length growth (mm)	47·1[a]	100	14·2[b]	30	10·7[b]	23
Feed consumption (g)	181·4[b]	100	242·4[a]	134	129·0[c]	71
Feed conversion	2·47[c]	100	11·88[b]	481	15·18[a]	615
Mortality (%)	2·2[a]	100	8·9[b]	405	7·8[b]	355

[a,b,c] Means in the same row with different superscripts differ ($P < 0{\cdot}05$).
[d] Means in each row expressed as percentages of the commercial diet mean.
[e] Initial body weight and total length determined from a random sample of 50 fish were 31·8 g and 124·8 mm.
[f] Determined as weight × 10^5/(Total length)^3.

Due to difficulties in measuring uneaten food, feed waste was not determined for any diet group so that actual efficiency values reported from here on as fed basis may be lower than computed. The low rate of weekly gain (2–3 g from 7–20 weeks in trial 2 and even less in trial 3) which resulted from feeding both whole and chopped larvae to both fish species may not justify the additional costs of the chopping process in a commercial operation. Soldier fly larvae and fish meal should be used in formulating isonitrogenous diets as well as supplementation with individual amino acids to investigate further if response is due to protein concentration or amino acid balance and not to a non-specific nitrogen. Larvae feeding in trial 3 was also associated with significantly greater mortality rates than feeding the commercial diet.

Further discussion

Feeding chopped or whole larvae severely depressed fish growth to less than one-third under a standard diet which suggests that fresh larvae alone does not contain sufficient nutrients to

Table 7. Average weekly gain (g), feed consumption (FC) and feed efficiency (FE) of tank-cultured channel catfish fed 100% whole or chopped soldier fly larvae from 7–20-week experimental period (trial 2)

	7–13 wks			13–20 wks			7–20 wks	
Diet	Gain	FC[a]	FE	Gain	FC[a]	FE	Gain	FC[a]
Whole	1·8	30·4	16·9	2·7	29·0	10·7	2·3	29·6
Chopped	2·6	35·4	13·6	3·4	45·1	13·2	3·0	40·6
%[b]	69·2	85·9	124·3	79·4	64·3	81·1	76·7	72·9

[a] Feed consumption values are measured in grams.
[b] Means of whole larvae fed catfish expressed as percentages of the means for chopped larvae group.

yield optimal growth. This is not consistent with the results of Bondari & Sheppard (1981). The following noticeable contrasts which existed between the two experiments may account for the inconsistency in the results: (1) polyculture with channel catfish in 1981 *vs* monoculture in the present study; (2) feeding a mixture of larvae and a commercial diet in 1981 *vs* feeding larvae, formulated or commercial feed alone in the present study; and (3) a difference in the length of the experimental period (10 weeks in 1981 *vs* 20 weeks in the present study). Food competition between the two fish species in polyculture (Bondari & Sheppard 1981) may have made tilapia a more aggressive feeder than channel catfish. They perhaps consumed more commercial feed than the channel catfish, which did not grow well in polyculture.

Results of the present study demonstrated that growth depression of the larvae-fed fish progressively increased with the length of the experimental period. A close examination of the trial 3 data indicated that the second 10-week growth results differed strikingly from the first 10-week results.

Feeding chopped or whole larvae did not provide sufficient dry matter or protein intake to support optimum growth of either channel catfish or blue tilapia. Incorporation of dried *H. illucens* larval meal into a poultry diet (Hale 1973) and a swine diet (Newton *et al.* 1977) produced growth comparable to diets containing similar quantities of meat and bone meal or soybean meal respectively. In this study, formulated diet containing 10% larvae produced growth rates superior to those of the 100% larvae meal. This again suggests that dry matter intake may have been a limiting factor in feeding these fresh larvae to channel catfish or blue tilapia.

Further research is needed to determine if improved nutritional performance justifies the cost of drying and pelleting larvae to increase the dry matter intake of the fish. This becomes significant when one realizes that large quantities of this high protein organism could be produced on waste or animal manure in many tropical or temperate zones of the world. As far as the fish products are concerned, Bondari & Sheppard (1981) reported that feeding soldier fly larvae to channel catfish or blue tilapia did not result in adverse effects on fish quality. Results of the taste panel evaluations in this study also confirmed no significant diet effect on taste quality of fish flesh.

One important consideration in this study was to demonstrate that poultry waste can be transformed into a usable fish product. The use of animal waste for the enrichment of fish ponds is a widespread practice (Stickney, Rowland & Hesby 1977; Buck, Baur & Rose 1978; Stickney, Hesby, McGeachin & Isbell 1979; Burns & Stickney 1980), but the use of soldier fly larvae to convert poultry manure into fish flesh is a new waste management technique recently reported by Bondari & Sheppard (1981). Results of the present study suggested that soldier fly larvae cannot successfully replace the fish meal component of the catfish diet and that larvae meal does not produce fish growth comparable to those resulting from commercial diets. However, the study demonstrated a potential use of soldier fly for the disposal of the waste generated by the rapidly growing poultry industry and the conversion of the waste into high quality fish products. Poultry manure is easily collected since it is generally produced in confinement and offers potential for methane gas production and fertilizing crops and pastures. Further research will be required to compare these waste-processing benefits to those of soldier fly production for fish food.

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