Bait and Ornamental Fish Nutrition

Rebecca Lochmann and Harold Phillips

University of Arkansas at Pine Bluff
Department of Aquaculture and Fisheries
P.O. Box 4912
Pine Bluff, Arkansas, USA 71611
Phone: (870) 575-8124
Fax: (870) 575-4639
E-mail: rlochmann@uaex.edu; hphillips@uaex.edu

Abstract

Small fish produced specifically for anglers to attract food or game fishes are referred to as "baitfish". This review addresses the nutrition and feeding practices for the three main species cultured in the U.S.: the golden shiner, *Notemigonus crysoleucas*, goldfish, *Carassius auratus*, and fathead minnow, *Pimephales promelas.* Goldfish and "rosy red" fathead minnows may also be marketed as "feeder" fish for piscivorous pets, and goldfish can be marketed as ornamental fish. In addition, fathead minnow is widely used as a toxicological and biomedical model. Multiple approaches are used to study nutrition in bait and ornamental fishes, as some spend most of their lives in ponds with access to live and prepared foods, while others are confined to aquaria and totally dependent on prepared diets. The nutritional and economic considerations are different in these scenarios, and diets must be developed and refined to address these diverse needs. Most of the research on bait and ornamental fishes has focused on macronutrients. Vitamin research has begun, but mineral nutrition is virtually unaddressed. In addition, research on feed additives (e.g., prebiotics and probiotics) that have the potential to enhance hardiness and prolong survival of bait and ornamental fishes throughout the production and marketing cycles has been initiated.

Rebecca Lochmann and Harold Phillips. 2006. Bait and Ornamental Fish Nutrition. En: Editores: L. Elizabeth Cruz Suárez, Denis Ricque Marie, Mireya Tapia Salazar, Martha G. Nieto López, David A. Villarreal Cavazos, Ana C. Puello Cruz y Armando García Ortega. Avances en Nutrición Acuícola VIII .VIII Simposium Internacional de Nutrición Acuícola. 15 - 17 Noviembre.
Universidad Autónoma de Nuevo León, Monterrey, Nuevo León, México. ISBN 970-694-333-5.

1. Introduction

Small fish produced specifically for anglers to attract desirable food or game fishes are referred to as "baitfish". This review addresses the nutrition and feeding practices for the three main species cultured in the U.S.: the golden shiner, *Notemigonus crysoleucas*, goldfish, *Carassius auratus*, and fathead minnow, *Pimephales promelas.* Goldfish and the rosy red variety of fathead minnows may also be marketed as "feeder" fish, which are meant for consumption by piscivorous pets, and goldfish can be marketed as ornamental fish. Fathead minnow is widely used as a toxicological and biomedical model in the laboratory. Regardless of their ultimate use, the culture conditions for these three Cyprinid species are similar when they are raised in outdoor ponds in the southern U.S. The market value of these species is determined primarily by size, which dictates production and marketing strategies. Small individuals comprise the bulk of fish used as bait, "feeders" or ornamentals.

The known nutritional requirements of baitfish species are similar to those of other warmwater fish that consume both animal and plant matter, such as channel catfish (*Ictalurus punctatus*) and common carp (*Cyprinus carpio*) (Lochmann & Phillips 2002). However, feeding practices for bait and ornamental fish differ from those of foodfish in several important ways (Table 1).

Table 1. Factors that affect feeding and nutrition of bait and ornamental fish versus channel catfish in ponds.

Factor	Bait & ornamental fish[1]	Channel catfish[2]
Feed Cost	18% of total costs	50 % or more of total costs
Fish Growth	Desired rate depends on target market sizes	Maximum rate is usually desired throughout production cycle
Natural Foods	Supply 40% or more of nutrition for non-fry stages in intensive culture when complete diets are used	Contribution uncertain; may provide some vitamins and minerals for non-fry stages in intensive culture when complete diets are used
Body Composition	Large amount of body fat does not reduce marketability/ may be an advantage	Large amount of body fat reduces dressout percentage
Appearance	Red-orange color desired for feeder & ornamental fish	White flesh color preferred

[1]Includes golden shiners, goldfish and fathead minnows.
[2]Robinson & Li (2002).

Rebecca Lochmann and Harold Phillips. 2006. Bait and Ornamental Fish Nutrition. En: Editores: L. Elizabeth Cruz Suárez, Denis Ricque Marie, Mireya Tapia Salazar, Martha G. Nieto López, David A. Villarreal Cavazos, Ana C. Puello Cruz y Armando García Ortega. Avances en Nutrición Acuícola VIII .VIII Simposium Internacional de Nutrición Acuícola. 15 - 17 Noviembre.
Universidad Autónoma de Nuevo León, Monterrey, Nuevo León, México. ISBN 970-694-333-5.

2. Relative importance of natural and prepared diets

Most baitfish producers encourage natural food production by using appropriate fertilization and monitoring regimes (Stone et al., 1997). Natural foods are inexpensive sources of protein, energy and micronutrients compared to prepared feeds. However, use of manufactured feeds greatly increases baitfish production, even when natural foods are present.

To estimate the relative contribution of natural and prepared foods to the nutrition of golden shiners, an 8-week feeding trial was conducted in 0.04-ha ponds using stable carbon isotope ratios, ($\delta^{13}C$) as nutrient tracers (Lochmann & Phillips 1996). Fish and their food items (both natural and artificial) contain a "signature" $\delta^{13}C$. Over time, the "signature" of the fish will most closely resemble that of the food item(s) that is/are most important in their diet. In this study, groups of 150 golden shiners (initial individual weight =1.4 g) were stocked into floating nets (0.33-cm mesh) in unfertilized ponds. The stocking density was comparable to an intensive level of 550,223 fish/ha. Three nutritionally similar diets with a range of $\delta^{13}C$'s were prepared at UAPB. Each diet was fed to fish in one net within each of four ponds at a rate of 4% body weight/day divided into two feedings. The $\delta^{13}C$'s of the fish and seston (suspended particulate matter including plankton) were measured at the beginning and end of the study. The ratios of the prepared diets were also measured. At the end of the study, the change in fish $\delta^{13}C$'s in combination with weight gain were used to estimate the relative importance of seston and the prepared diets to the nutrition of the golden shiners. Even when nutritionally complete feeds were fed twice daily, the fish still derived 40-83% of their nourishment from the seston (Table 2). This established the large contribution of natural foods to the nutrition of golden shiners at a fixed stocking density when the natural food supply was uniform between treatments. However, factors such as stocking density and the quality and quantity of plankton blooms vary widely in commercial baitfish ponds. Some of this variability is seasonal, but even within a season some ponds develop and "hold" a good bloom and some do not.

Table 2. The calculated contribution of seston[1] to the weight gain of golden shiners fed isotopically distinct diets in ponds

Diet number	Diet $\delta^{13}C^{2}$	Average individual weight gain (g)	Pond contribution (%)[3]
1	-24.4	1.01	40.4
2	-21.3	0.96	57.0
3	-16.3	0.93	83.1

[1] Seston is suspended particulate matter, including plankton.
[2] $\delta^{13}C$ is the ratio of $^{C13}/_{C12}$ stable carbon isotopes found naturally in the diets.
[3] See Lochmann & Phillips (1996) for details.

When the amount of natural food per fish is reduced (either because there are more fish in the pond, or the natural food is scarce), prepared diets may become a more important nutrient source for baitfish. The effect of production variables such as stocking density, natural productivity (measured by secchi disk), dissolved oxygen and feeding rate on use of foods by golden shiners

Rebecca Lochmann and Harold Phillips. 2006. Bait and Ornamental Fish Nutrition. En: Editores: L. Elizabeth Cruz Suárez, Denis Ricque Marie, Mireya Tapia Salazar, Martha G. Nieto López, David A. Villarreal Cavazos, Ana C. Puello Cruz y Armando García Ortega. Avances en Nutrición Acuícola VIII .VIII Simposium Internacional de Nutrición Acuícola. 15 - 17 Noviembre.
Universidad Autónoma de Nuevo León, Monterrey, Nuevo León, México. ISBN 970-694-333-5.

in ponds was examined in simultaneous 8-week feeding trials at the University of Arkansas at Pine Bluff (UAPB) and Texas A&M University (TAMU) (Lochmann et al., 2001). Ten 0.04-ha ponds per site were fertilized with defatted rice bran and stocked with golden shiners (initial weight=1.3 g) at a rate of 759,110 fish/ha (UAPB) or 379,555 fish/ha (TAMU). Fish in five ponds per site were fed a nutritionally complete prepared diet at 4% of body weight, while fish in the remaining ponds were not fed. Assimilation of natural foods by "unfed" fish was compared to that of fish fed the prepared diet at each site. Standard production data (weight gain, Secchi depth, dissolved oxygen (DO)) was compared to stable carbon isotope ratio ($\delta^{13}C$) data as an index of fish performance (weight change or fish $\delta^{13}C$, resulting from assimilation of various food sources). Natural productivity (plankton) was consistently lower at TAMU than at UAPB, while temperature and minimum DO was similar between sites. Weight gain of fed and unfed fish stocked at a lower density at TAMU was higher than that of fed and unfed fish, respectively, stocked at a higher density at UAPB. The $\delta^{13}C$ of fed and unfed fish at UAPB changed little during the study, so stable isotopes could not be used to provide any information about their food sources. The $\delta^{13}C$ of fed fish at TAMU approached that of the prepared diet, while that of unfed fish resembled that of the plankton and rice bran. The amount of prepared diet significantly affected fish weight change, but Secchi depth and minimum DO did not. Weight gain increased with increasing feed amount up to a maximum value, and then declined with additional inputs (Figure 1).

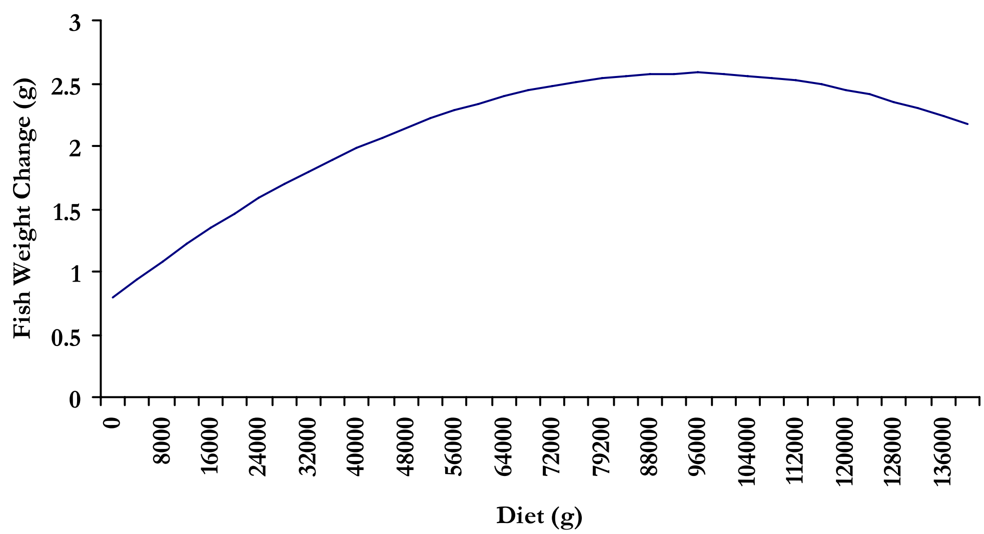


Figure 1. Weight change of fed golden shiners versus diet quantity offered in ponds at two sites during an 8-week feeding trial.

Minimum DO, plankton isotope ratio, and the fed/unfed variables significantly affected fish isotope ratio. This experiment highlighted the importance of two issues: 1) Decreased growth of golden shiners at high stocking rates is associated with, not counteracted by, high feed inputs); and 2) There is greater use of prepared diet by fish at lower densities when natural productivity in ponds is low. The cause of the growth reduction observed at high fish densities despite heavy

Rebecca Lochmann and Harold Phillips. 2006. Bait and Ornamental Fish Nutrition. En: Editores: L. Elizabeth Cruz Suárez, Denis Ricque Marie, Mireya Tapia Salazar, Martha G. Nieto López, David A. Villarreal Cavazos, Ana C. Puello Cruz y Armando García Ortega. Avances en Nutrición Acuícola VIII .VIII Simposium Internacional de Nutrición Acuícola. 15 - 17 Noviembre.
Universidad Autónoma de Nuevo León, Monterrey, Nuevo León, México. ISBN 970-694-333-5.

feeding in this study was not clear. Both living (e.g., plankton) and non-living (e.g., ammonia) components of water quality can become degraded with heavy feed inputs, which could inhibit fish growth directly. In addition, some cyprinid fishes secrete chemical substances that inhibit growth when they are crowded. Additional research is needed to determine the specific cause(s) of growth reduction in golden shiners at high densities when feeding appears to be adequate to support a higher growth rate.

3. Macronutrients in prepared diets

Fish need energy to maintain basic metabolic activities, and to support growth, reproduction, activity and health. Proteins, carbohydrates and lipids provide this energy, but there are no estimates of available energy from different diet ingredients for golden shiner, goldfish, or fathead minnow. Instead, available energy has been estimated mostly from growth on particular diets under specified conditions.

3.1. Proteins

Fish require essential amino acids in proteins for growth, tissue repair, general health and reproduction. Protein source has a major impact on diet cost. Therefore, both the amount and source of protein must be considered when formulating optimal diets for bait and ornamental fish.

3.1.1. Dietary protein concentration

The total dietary protein requirement may be defined as the minimum amount of protein that produces best fish performance (e.g., growth, feed conversion) under a given set of conditions. The total dietary protein requirement is most important economically, since protein is the most expensive component of diets. In addition to total protein, the balance between protein and energy in a diet is critical. When more protein is added to a diet than is needed for growth and other bodily functions, the excess will be metabolized for energy or used to make energy-storage products (e.g., body fat). Other diet components (carbohydrate or fat) should be used to supply energy because they are usually less expensive. Excess energy in the diet can also reduce feed consumption and growth.

The total dietary protein requirement and the protein:energy ratio of golden shiner and goldfish were examined in separate experiments (Lochmann & Phillips 1994a). Juvenile golden shiners and goldfish (0.2 grams in mean initial weight) in aquaria were fed semi-purified diets containing graded levels of protein. Weight gain, survival and feed efficiency of golden shiners and goldfish fed the diet with 29% protein was similar to that of fish fed diets with higher protein levels (up to 34%) when fed at 4-7% of body weight. The ideal dietary energy:protein ratio for growth of golden shiners and goldfish in aquaria was 9.7 kcal of digestible (available) energy per gram of dietary protein. We used analysis of variance to analyze this data. Different dietary protein estimates can be obtained if regression analysis is applied. However, observations from numerous aquarium and pond studies at the University of Arkansas at Pine Bluff (UAPB) indicate that 29% protein is a valid estimate of the minimum dietary requirement for growth of this species.

In ponds, natural foods contribute to the total amount of protein and energy available to fish, so results might differ from aquarium studies. Therefore, an experiment was conducted to determine the effect of different dietary protein:energy ratios on production of golden shiners in ponds (Lochmann & Phillips 2001a). Golden shiners (1.24 g in mean initial weight) were fed diets similar in energy:protein ratios but different in total protein levels (22 or 28%) to satiation twice daily for 10 weeks. Weight gain of fish fed the diet with 28% protein was higher after four weeks, but by 10 weeks there were no significant differences in weight gain, feed conversion, gross yield, or yield of individual size classes of fish (not shown) fed the two diets (Table 3). The fish fed the diet lower in protein and energy might have consumed more feed than fish fed the diet higher in protein and energy, causing similar production between the two groups. Feed intake was difficult to measure in this study because the two diets differed in pellet flotation. However, most commercial high-protein diets are more expensive than low-protein diets. Therefore, if the fish eat more of the low-protein diet, the production costs of using either diet may be similar. With food fish such as channel catfish, lower-protein diets usually produce undesirable increases in visceral fat. This will not be an issue with bait or ornamental fish. Nevertheless, economic analyses of the golden shiner data and additional studies with other species are required before lower-protein diets can be recommended for standard use.

Table 3. Performance of golden shiners in ponds fed diets differing in lipid source and amount for 10 weeks.[1]

Dietary protein (%)	Energy:protein ratio[2]	Mean individual weight gain (g)	Gross yield (kg)	Feed Conversion
22	11.5	3.5±0.6	34.2±6.0	2.5±0.4
28	11.2	3.9±1.0	28.8±7.4	3.1±0.9

[1] Performance data are means (±SD) of 4 ponds each stocked at a rate of 937,702 fish/ha. Individual fish averaged 1.24 grams initially. Means were not significantly different between treatments ($P>0.05$).
[2] Digestible energy values for channel catfish for individual feed ingredients (NRC 1993) and analyzed dietary protein data were used to calculate the E:P ratio.

3.1.2. Dietary protein source

Aside from total dietary protein, protein quality also affects fish performance. The amount and types of amino acids in a protein source determine its quality. The quantitative amino acid requirements of baitfish have not been determined. However, the essential amino acid patterns of whole-body golden shiners, goldfish and fathead minnows (Gatlin 1987) are similar to those of channel catfish and common carp, indicating that the essential amino acid requirements are similar for these species.

In practical diets for baitfish, soybean meal is the main protein source because its amino acid content is well balanced, and it is widely available and less expensive than other complete protein sources like fish meal. Several studies with baitfish have shown that fish meal does not provide any obvious benefits over soybean meal as a dietary protein source. A series of studies by Gannam (1992) found that there were no differences in weight gain or yield of golden shiners in ponds fed practical diets with only vegetable proteins versus diets with 5, 10 or 20% fish meal. The primary vegetable protein source for all diets was soybean meal. In another experiment, the relative quality of different protein sources was compared in a 7-week feeding trial with practical diets fed to golden shiner shiners (0.2 g in mean initial weight) in aquaria (Lochmann and Phillips 2001a). Worm meal was similar to fish meal in its effect on growth of golden shiners, but growth of golden shiners fed the soybean-meal diet with no animal protein was as good as that of fish fed diets with animal protein (Table 4). The combined results of aquarium and pond trials indicate that animal protein sources are not critical in practical diets for growth of golden shiners.

Table 4. Performance of juvenile golden shiners fed diets differing in protein source for 8 weeks.[1]

Protein variable (%)	Mean initial weight (g)	Mean individual weight gain (g)	Survival (%)	Whole-body protein (%)
No animal protein(45% soybean meal)	0.23	0.61[a]	98	50.3[ab]
Fish meal (5.0)	0.23	0.61[a]	100	49.9[ab]
Worm meal (5.1)	0.23	0.47[b]	100	52.5[a]
Fish meal (10.0)	0.23	0.71[a]	99	47.3[b]
Worm meal (10.7)	0.23	0.70[a]	90	52.7[a]

[1]Values are means of 3 groups of 30 fish each. Means within columns with different superscript letters are significantly different (P<0.05) as determined by Fisher's LSD test.

3.2. Lipids

Fish do not require lipids specifically, but they need and cannot make several components that are found only in lipids. These include the essential fatty acids (EFA). The EFA are required for normal growth, health, and reproduction, and they must be provided in the diet. Some fish also require a dietary source of phospholipid such as soybean lecithin, especially at very early stages (Hertrampf 1992). Lipids must be present in the diet for normal absorption of fat-soluble vitamins (A, D, E, K). They are energy dense compared to proteins or carbohydrates and may be less expensive than proteins, depending on current market prices for different sources. The potential to use dietary lipid to spare protein for growth may be greater in bait and ornamental fishes, where increases in body fat associated with consumption of high-fat diets does not usually reduce market value.

3.2.1. Amount

The optimal dietary lipid level for juvenile golden shiners and goldfish was determined in a series of experiments (Lochmann & Phillips 2002). In separate feeding trials, golden shiners and goldfish in aquaria were fed purified diets with graded levels of a mixture (50/50%) of cod liver and soybean oils. The lipid mixture contained fatty acids of the n-3 and n-6 families which meet the EFA requirements of most fish species. Weight gain of golden shiners fed diets containing 34% protein and 7-12% lipid was higher than that of fish fed diets with lower or higher lipid levels. Survival of golden shiners fed diets with 4.6-14.8% lipid in aquaria was 92% or higher, and feed efficiency was similar among diets. Weight gain and feed efficiency of goldfish declined as dietary lipid increased from 4.5 to 13.3%. The highest lipid level (13.3%) significantly reduced weight gain relative to fish fed diets with 7.1% lipid or less. The highest lipid level (13.3%) significantly reduced feed efficiency relative to fish fed diets with 8.9% lipid or less. Survival increased with dietary lipid level, but was 93% or higher in all treatments.

Golden shiners in aquaria fed practical diets with the same amount of protein and total calories, but either 4% or 13% poultry fat for 7.5 weeks had similar growth. However, survival was significantly higher in fish fed the diet with 13% lipid. The reason for the difference was unknown. Trials using similar diets in outdoor systems were conducted for comparison.

Golden shiners (0.9 g individual weight) in ponds (0.04-ha) stocked at 778 kg/ha were fed supplemental practical diets containing 4 or 13% poultry fat, or 13% menhaden fish oil to satiation twice daily for twelve weeks (Lochmann & Phillips 2001a). Weight gain of golden shiners fed the diet with 4% poultry fat was higher than that of fish fed either diet with 13% lipid. Thus, no protein-sparing effect was observed in this study. Net yield of fish fed the three diets was similar, implying a higher survival rate among fish fed the diets with 13% lipid. Whole-body lipid of the golden shiners fed the diet with 13% menhaden fish oil was higher than that of fish fed the diets with 4 or 13% poultry fat. This implies a difference in metabolism of poultry and fish oils by golden shiners, which needs further study.

Goldfish (0.9 g individual weight)) stocked at 600 fish per fertilized pool (4137-L) were fed practical diets containing 4 or 13% lipid as poultry fat or menhaden fish oil at 3-6% BW for nine weeks (Lochmann and Phillips 2001a). These supplemental diets contained 24% protein and no added vitamins or minerals. Average individual weight gain, feed efficiency, net yield and whole-body lipid were significantly higher in goldfish fed either diet with 13% lipid, compared to fish fed diets with 4% lipid (Table 5). Lipid source did not affect goldfish performance. It is likely that the improved performance of goldfish fed the high-lipid diets was due to protein sparing by the lipid. The prepared diets contained only 24% protein, but the plankton might have provided extra protein which was used for growth since energy was provided by the lipid in the prepared diet.

Table 5. Performance of goldfish in pools fed diets differing in lipid amount and source for 12 weeks.[1]

Dietary lipid (amount, source)	Mean individual weight gain (g)	Net Yield (g)	Feed Conversion	Whole-body lipid (%)
4% Poultry fat	0.67^{B}	309^{B}	3.0^{B}	6.3^{ab}
4% Menhaden fish oil	0.65^{B}	312^{B}	3.0^{B}	5.4^{b}
13% Poultry fat	0.82^{A}	378^{A}	2.5^{A}	7.5^{ac}
13% Menhaden fish oil	0.71^{AB}	338^{AB}	2.7^{AB}	7.9^{c}

[1]Values are means of 4 pools each stocked at a rate of 1 million fish/ha. Individual fish weighed 0.4 grams initially. Means within columns with different lower case superscript letters are significantly different at P=0.05. Means within columns with different numbers of upper case superscript letters are significantly different at P<0.10. Differences were determined by Fisher's LSD test.

3.2.2. Source

Studies have also been conducted in aquaria to determine the specific type (n-3, n-6, or both) of essential fatty acids (EFA) required by golden shiners fed purified diets. Different lipids provide different types and amounts of fatty acids. For instance, fish oil contains large amounts of long-chain n-3 fatty acids which originate from algae. These are required by most marine and carnivorous fish. Freshwater fish can generally make the long-chain n-3 fatty acids from shorter n-3 fatty acids found in oils like canola or soybean oil. Fish oil, algae and some fungi also contain substantial amounts of long-chain n-6 fatty acids from which biochemicals (e.g., prostaglandins) involved in inflammatory processes, immune function, reproduction and other critical functions are made. Freshwater fish can usually make the long-chain n-6 fatty acids from shorter n-6 fatty acids found in lipids like poultry fat or soybean oil. Both the n-3 and n-6 fatty acids are probably required for baitfish species.
Results of studies to determine the EFA requirements of golden shiners are summarized in Table 6.

Table 6. Summary of studies at UAPB to determine the types of fatty acids needed by golden shiner.[1,2]

Study length/ Initial weight	Lipid sources	Main results[3]
9 wks/	soybean, rice bran, canola,	No differences in WG or SURV by diet;
0.21 g	cod liver, poultry	whole-body lipid was higher in fish fed vegetable versus animal lipids
11.5 wks/ 0.19 g	soybean, rice bran, canola, cod liver, poultry, olive	No differences in WG or SURV by diet; SURV of fish stressed with low DO was highest in fish fed SBO
6 wks/	soybean, canola, cod liver,	WG of fish fed the SBO+CLO, olive, and SBO
0.35 g	soy+cod liver (50/50%), olive	diets was highest; no differences in SURV; FA composition of fish body similar to diet
34 wks /0.22 g	Same as above	No differences in WG by diet; Fish fed CAN had intact fins, skin and gill covers - those fed olive oil had obvious erosion in these areas; fish fed other lipids were intermediate in appearance

[1]Source: Lochmann & Phillips (2001b).
[2]Purified diets for all experiments contained 10% lipid, 34% protein and 10 kcal energy/g of protein from casein and gelatin. The different lipid sources were chosen because they contained a variety of fatty acids known to be essential for other fish.
[3]Abbreviations are: WG, weight gain; SURV, survival; DO, dissolved oxygen; SBO, soybean oil; CLO, cod liver oil; FA, fatty acid; CAN, canola.

These trials have not consistently indicated a specific requirement for n-3 or n-6 fatty acids. Similar studies with common carp, channel catfish, and tilapia also had conflicting results. One study showed that growth and survival of larval goldfish fed diets with cod liver or canola oils was equally good, indicating that a dietary source of long-chain n-3 fatty acids (such as those in fish oils) is not required. However, that study did not consider n-6 fatty acids. Prostaglandins derived from n-6 fatty acids stimulate steroid (sex hormone) production in goldfish, and courtship behavior in fathead minnows. Baitfish probably get substantial amounts of EFAs from natural foods in ponds under most production conditions. However, until the qualitative and quantitative EFA requirements of baitfish are established, dietary sources of both n-3 and n-6 fatty acids should be provided to support normal growth, health, appearance and reproduction in these species. Of the fat sources readily available in Arkansas, poultry fat is a good source of n-6 fatty acids but contains very few n-3 fatty acids. Soybean oil and soybean lecithin (a mixture of phospholipids) contain 7-8% of the n-3 fatty acids and are also high in n-6 fatty acids. Soybean lipids (oil and/or lecithin) alone or blended with poultry fat should satisfy the EFA requirements of baitfish for growth.

Phospholipids are important structural components of cell membranes. The EFAs from the diet are incorporated into the phospholipids where they help regulate membrane permeability and serve as sources of eicosanoids. Adult fish can synthesize phospholipids, but larval or juvenile fish may benefit from having a dietary source. Soybeans are the primary commercial source of feed-grade lecithins (mixtures of phospholipids). Practical baitfish diets supplemented with soybean lecithin enhanced growth but did not affect survival of juvenile goldfish relative to diets containing lipid as triglyceride from either soybean or fish oils (Lochmann & Brown 1997). Phospholipids may improve lipid digestion, absorption and transport in baitfish, as in other fish.

3.3. Interactions between dietary protein and lipid sources

We measured growth, survival, feed conversion, and response to low dissolved oxygen of adult fathead minnow in tanks fed practical diets with animal (menhaden fish meal and poultry by-product meal) or plant (mostly soybean) protein sources, and either poultry oil or menhaden fish oil for 12 weeks (Lochmann & Kumaran 2006). Good weight gain (0.6 – 0.8 g) was obtained either with vegetable-protein or animal-protein sources. Poultry oil enhanced growth relative to menhaden fish oil in diets with either vegetable- or animal-protein sources. Mean survival of fish fed the animal-protein and vegetable-protein diets was 88% and 96%, respectively, and was not affected by lipid source. Survival during the low-oxygen stress test was high ($\geq$90%) across diets, but survival was lower in fish fed the animal-protein diet with PO than the animal protein diet with MFO. Vegetable proteins and poultry oil are promising alternatives to more costly diet ingredients in practical diets for fathead minnow.

3.4. Carbohydrates

Unlike proteins and lipids, carbohydrates do not contain specific factors known to be essential for fish. However, they are valuable as inexpensive energy sources in the diet. The types of carbohydrates that are readily available to monogastric (simple-stomached) animals such as fish are sugars and starches. Starches are the main source of available carbohydrates from practical feedstuffs.

3.4.1. Amount

Weight gain and survival of golden shiners fed laboratory (semi-purified) diets differing in starch content (15, 30 or 45%) and lipid (15, 8.3 or 1.7%) was similar, indicating that they perform well over a wide range of dietary carbohydrate: lipid ratios (1:1 to 27:1) (Lochmann & Phillips 2002). The incorporation of different amounts of lipid and starch into the fish tissues (whole body) was evident when the stable carbon isotope ratios of fish and dietary lipids and starches were compared.

3.4.2. Source

In another experiment, weight gain of golden shiners fed diets with 15% carbohydrate from different sources improved with increasing complexity of the carbohydrate: starch>dextrin>sucrose=glucose (Table 7)(Lochmann & Phillips 2002). Results are similar to those for other warmwater omnivorous fish. As stated previously, starches are the main source of available carbohydrate in fish feedstuffs. However, the availability of carbohydrate energy from practical feedstuffs is likely to be different from that of purified ingredients (e.g., corn starch), and this needs to be addressed in bait and ornamental fish.

Table 7. Performance of juvenile golden shiners fed diets with 15% soluble carbohydrate from different sources for 8 weeks [1,2]

Dietary carbohydrate source	Mean individual initial weight(g)	Mean individual weight gain (g) (%)	Survival
Dextrin	0.33	0.84[b]	98.9[a]
Corn starch	0.33	0.97[a]	96.7[ab]
Glucose	0.33	0.64[c]	98.9[a]
Sucrose	0.34	0.61[c]	93.3[b]

[1]Values are means of three groups of 30 fish per group.
[2]Means with different superscripts are significantly different ($P<0.05$) as determined by Fisher's protected LSD test.

4. Micronutrients in prepared diets

Vitamins are organic compounds required in small amounts for normal growth, health and function. They are classified as fat soluble (A,D,E,K) or water soluble (B vitamins, C, etc.). Requirements vary with fish species, age, size, and physiological state (e.g., stress, reproductive status). Fish larvae reportedly can absorb some vitamins directly from the water, but natural foods rich in vitamins are also heavily consumed by baitfish larvae. Obvious vitamin deficiencies are not common in pond-raised baitfish of any size, probably due to the continued importance of natural foods throughout the production cycle. However, the amounts and types of natural foods and their vitamin content vary seasonally and over time. Also, the amount of natural food per fish is lower at high fish densities (intensive stocking densities). In addition, commercial baitfish diets contain mostly plant ingredients since they are cheaper than animal ingredients, but animal ingredients are better sources of fat-soluble vitamins. These are valid reasons to supplement commercial baitfish diets with the same types and amounts of vitamins and minerals used in diets for channel catfish. However, studies with channel catfish have shown that some of the supplemental vitamins can be reduced or eliminated from commercial diets without reducing fish yield or quality (Robinson, Li & Oberle 1998). Therefore, more research is needed to determine suitable levels of supplemental vitamins for commercial baitfish diets.

4.1.1. Vitamin-mineral supplement in diets for pond-reared golden shiner

Weight gain and total net yield of golden shiners in ponds fed diets with or without a combination vitamin and mineral supplement for 8 weeks did not differ (Table 8)(Lochmann & Phillips 1994b).

Table 8. Performance of golden shiners in ponds fed diets with or without a vitamin/mineral supplement for 8 weeks.[1]

Diet[2]	Mean group weight gain (kg)	Net yield (kg/ha)	Feed Conversion	Survival (%)
Unsupplemented	42.2	895.4	1.9	81.6
Supplemented	47.4	896.3	1.8	68.7

[1]Values are means of 4 ponds each stocked at a rate of 340.2 kg/ha. Individual fish weighed 0.6 grams initially. There were no significant differences between treatments ($P>0.05$).
[2]The unsupplemented diet contained no added vitamins or minerals. The supplemented diet contained 3% of a vitamin/mineral premix (Lochmann & Phillips 1994b) and 0.05% of stabilized vitamin C.

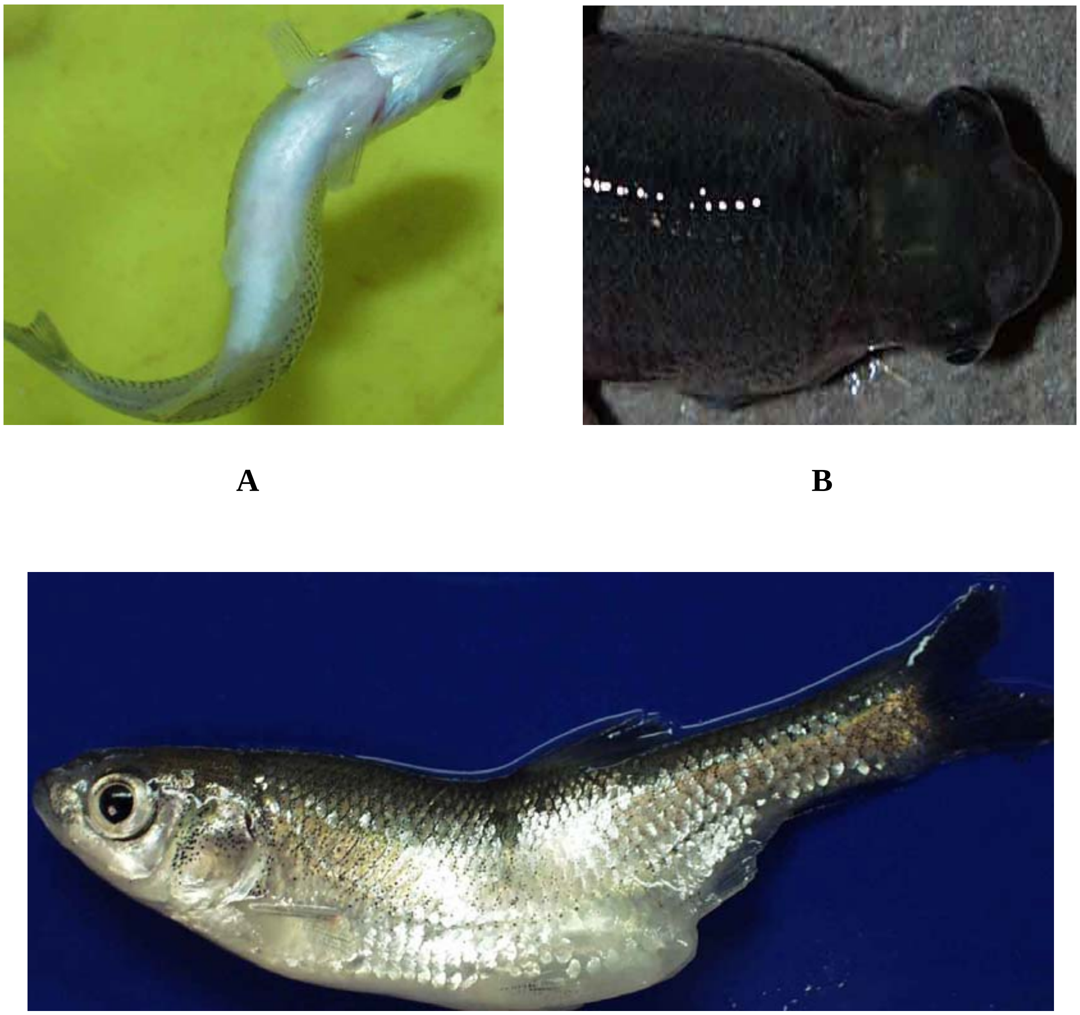
Presumably, natural-food consumption supplied sufficient vitamins and minerals to maintain overall fish production. However, diet affected the yield of fish in one size class - there were significantly more fish measuring 0.91 – 1.07 cm in width (grader size 23-27) from the ponds receiving diet 2 (with the supplement) than in those that received the unsupplemented diet. Some vitamins (C, E, A) also affect the immune system, and specific indices of health were not measured in this study. Performance of baitfish after harvest (during transport and marketing procedures) also could be affected by dietary vitamin intake during pond production, and this has not been studied.

4.1.2. Establishing a need for dietary vitamin C in golden shiner

Baitfish cultured indoors presumably need a source of vitamin C in the diet. An aquarium study was done to address this issue in golden shiners (0.5 g individual weight) (Lochmann, Dabrowski, Moreau, & Phillips 2001). Diets with casein (milk protein) or fish meal and either 0 or 250 mg/kg of vitamin C (Stay-C, Roche Vitamins, Inc.) were fed to golden shiners for 12.5 weeks. Weight gain was higher but survival of golden shiners was not affected by vitamin C in fish fed the fish-meal diets. Conversely, weight gain was not affected but survival was improved by vitamin C in fish fed the casein diets. Fish fed the casein diet were also infected with *Columnaris* during part of the study. This unplanned challenge to their immune system might explain the difference in results between the fish fed the fish-meal and casein diets, since vitamin C is known to stimulate the immune system. We concluded that the dietary vitamin C requirement for golden shiner is influenced by diet composition and health status.

4.1.3. Optimal dietary vitamin C concentrations for different functions in golden shiner

We determined the effects of different dietary concentrations of vitamin C (ascorbic acid; AA) on the growth and health of golden shiners fed diets with 0-218.5 mg AA/kg diet for 10-16 wk (Chen, Lochmann, Goodwin, Praveen, Dabrowski, & Lee 2003). Weight gain, survival and gross deformities were assessed at 10 wk. The remaining fish were maintained on the same diets from wk 11-16, then hematology and alternative complement activity were assessed and a subset of live fish from each tank was exposed to elevated temperature. Gross deformities were clearly tablished in fish fed 0 mg AA/kg diet for 10 weeks (Figure 2).



A B

C

Figure 2. Golden shiners exhibiting: A. Lateral spinal curvature (scoliosis); B. Exophthalmia and depigmentation; C. Dorsoventral spinal curvature (lordosis); after consuming a diet with 0 mg of ascorbic acid/kg diet for 10 weeks.

19.5 mg AA/kg diet was sufficient to prevent the deformities and optimize survival, while growth did not differ among treatments. Fish fed 40.3 mg of AA/kg diet had higher survival than fish fed 0 or 19.5 mg AA/kg diet following exposure to elevated temperature (35.5^{o}C). Alternative complement activity was highest in fish fed diets with 218.5 mg AA/kg. The results indicate that the dietary requirement of AA for golden shiners increases in response to heat stress, and that the alternative complement activity (one index of immune competence) was strongly enhanced in fish fed a diet with approximately 10 times the amount of AA needed to prevent deficiency signs.

4.1.4. Interaction between dietary vitamins C and E in golden shiner

We characterized the response of golden shiner fed one of eight purified diets with either 0 or 38 mg α-tocopherol (α-T) kg^{-1} and one of four levels of ascorbic acid (AA) (23, 43, 98, or 222 mg kg^{-1} diet) in a 2 X 4 factorial design (Chen et al., 2004). Growth, survival, signs of vitamin-E deficiency, and immune and stress responses were monitored in groups of 30 golden shiners (individual initial weight = 0.79g) fed the diets to apparent satiation twice daily in triplicate aquaria for 14-19 weeks. The average individual weight gain was not affected by dietary α-T concentrations at 14 weeks, but the survival of fish fed the α-T-unsupplemented diets was lower than that of fish fed the α-T-supplemented diets. After 10 weeks fish fed the α-T-unsupplemented diets began to show vitamin-E-deficiency signs such as increased prevalence of fish with darkened skin, muscular atrophy and dermal hemorrhaging (Figure 3).

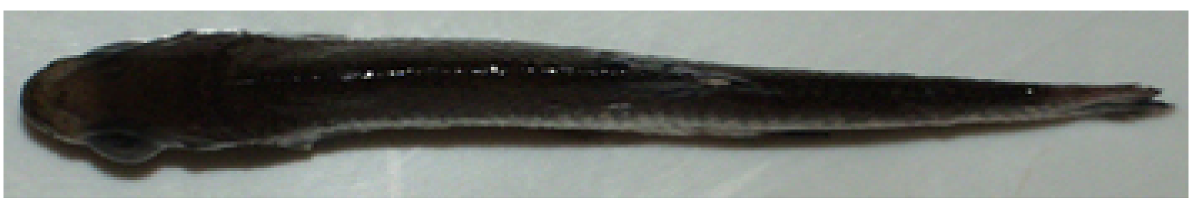
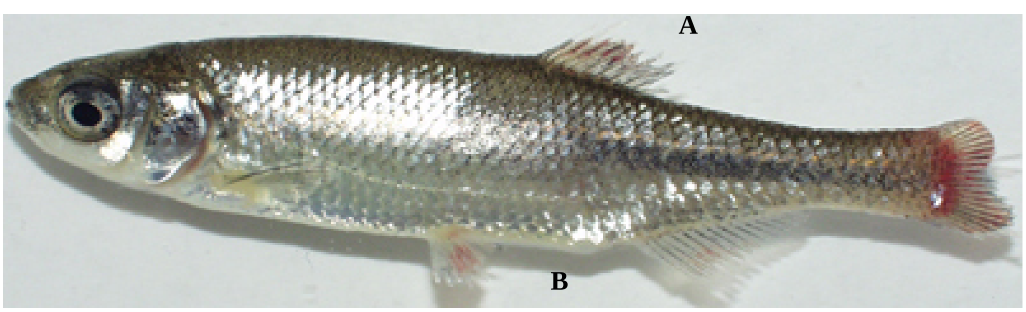


Figure 3. Golden shiners exhibiting: A. Reduction in epaxial muscle (muscular atrophy) and dermal melanization; B, Hemorrhaging on the fins, and dermal depigmentation; after consuming a diet with no supplemental vitamin E for 10 weeks.



Rebecca Lochmann and Harold Phillips. 2006. Bait and Ornamental Fish Nutrition. En: Editores: L. Elizabeth Cruz Suárez, Denis Ricque Marie, Mireya Tapia Salazar, Martha G. Nieto López, David A. Villarreal Cavazos, Ana C. Puello Cruz y Armando García Ortega. Avances en Nutrición Acuícola VIII .VIII Simposium Internacional de Nutrición Acuícola. 15 - 17 Noviembre.
Universidad Autónoma de Nuevo León, Monterrey, Nuevo León, México. ISBN 970-694-333-5.

After 17 weeks the deficient fish had lower α-T concentrations in viscera, lower whole-body crude protein, total lipid, dry matter, hematocrit, hemoglobin, lymphocyte (%), alternative complement activity (ACH50), and survival after exposure to stressful water temperatures (36-37 °C) than those fed the α-T-supplemented diets. A sparing effect of vitamin E on vitamin C was evident. Elevated dietary vitamin C reduced the incidence and severity of vitamin E deficiency signs in a dose-dependent manner. The interactive effect of vitamins C and E on ACH50 activity and percentage of thrombocytes was also significant . Regardless of vitamin E levels, different vitamin C levels did not influence the α-T concentration in viscera and other interactions between vitamins C and E were not evident.

4.1.5. Need for additional micronutrient research in bait and ornamental fish

Minerals are inorganic substances required in small amounts for normal growth, health and function. Mineral nutrition of baitfish has not been addressed in our lab. Presumably, it is similar to that of other cyprinid fishes. The mineral content of practical diets is based on requirements for channel catfish (NRC 1993), but baitfish may have different requirements. Cyprinid fishes (including golden shiner, goldfish and fathead minnow) do not have true stomachs that secrete acid to enhance digestion. Mineral availability from diet ingredients may be reduced in fishes that lack acidic digestion. In addition, commercial diets for bait and feeder fish raised in ponds contain mostly plant ingredients, and this trend is intensifying. Minerals from plant ingredients tend to be less bioavailable than those from animal ingredients (Davis and Gatlin 1996).

Additional basic studies to determine both mineral and vitamin requirements of different species of bait and ornamental fish for growth, survival, optimal health and reproduction are needed. Applied studies in outdoor systems are necessary also, due to the reliance of these fish on natural foods that supply many of the micronutrients.

5. Practical feeding regimes

5.1. Practical diets

Most semi-intensive and intensive producers use nutritionally complete diets to double or triple production of baitfish. The composition of diets used for different stages of the baitfish production cycle are similar to those for channel catfish. Soybean meal (48% protein, solvent-extracted) is the primary protein source in commercial baitfish feeds and very little (2-5%) fish meal is used in diets for juveniles and adults. There is no research-based reason to use fish meal, and the oil in marine fish meal is also more prone to oxidation than other lipids. Fresh poultry fat (as indicated by low peroxide and TBARS values) is frequently added to baitfish diets in Arkansas due to the proximity of the baitfish and poultry industries. Poultry fat appears to be palatable and has no known anti-nutritional properties for baitfish. However, baitfish may benefit from a mixture of fats (such as poultry fat and soybean oil), which provides a greater variety of essential fatty acids than any single lipid source. High-fat (13%) diets with lower protein levels (24%) have generated some interest among baitfish producers. The cost of increased dietary lipid may be offset by the reduction in cost due to the lower protein content, depending on current market prices for different ingredients. Until the nutrient requirements of baitfish are defined further, a nutritionally complete commercial catfish feed formulation with 28% protein and 5% added fat (as soybean oil and/or poultry fat) should support weight gain and fish health during growout under most production conditions.

5.1.1. Special diets: color enhancement

For feeder and ornamental fish, economical means of enhancing skin color are needed. The primary pigment responsible for the desirable reddish-gold color of goldfish is astaxanthin. This carotenoid pigment cannot be synthesized by the fish and must be provided in the diet. Astaxanthin is found naturally in algae. However, when plankton blooms are poor, supplementation of prepared feeds with carotenoids may prevent color loss or enhance color development of goldfish and rosy-red fathead minnow in ponds. Typical commercial diets used for pond culture of bait and feeder fish are very low in total carotenoids (<7 mg/kg).

Three feeding trials were conducted to investigate the effect of astaxanthin or lycopene supplementation of practical diets on performance of goldfish (Thyparambil 2004). In trial 1, duplicate groups of 100 uniform juvenile goldfish with mean initial weight of 0.38 g were reared in outdoor ponds and fed diets containing 2.8, 66.0, or 100 mg astaxanthin/kg diet, or 50 or 100 mg lycopene/kg diet for 71 d. In trial 2, goldfish from trial 1 were used to conduct an indoor washout study which consisted of two subtrials (2a and 2b). In subtrial 2a, goldfish were fed the same diet as in trial 1 while in subtrial 2b the goldfish were fed only the basal diet (2.8 mg astaxanthin/kg diet). In trial 3, fifty juvenile goldfish with an average initial weight of 0.77 g were reared in 25 110-L aquaria and fed the same diets as in trial 1 for 49 d. In trial 1, there was no significant difference ($P>0.05$) in average individual weight gain, survival, L*,a*,b*,C* or H* of fish fed different diets. In subtrials 2a and 2b, there were no significant differences in change in lightness (ΔL*), redness (Δa*), yellowness (Δb*), chroma (ΔC*) or hue (ΔH*) after the washout study period. In trial 3, there were no significant differences in average individual weight gain and survival among treatments. However, goldfish fed diets containing 100 mg astaxanthin/kg had significantly higher ($P\leq 0.05$) a* (red) than all other treatments (Table 9) while there were no significant differences in other color parameters. Data indicated that dietary astaxanthin supplementation is necessary for enhanced coloration of goldfish in the absence of natural foods.

Table 9. Lightness (L*), redness (a*), yellowness (b*), chroma (C*) and hue (H*) of goldfish fed practical diets containing different concentrations of astaxanthin (Astax) or lycopene (Lyco) for 49 days.[1]

Diet	L*	a*	b*	C*	H*
2.8 Astax	77.07±1.59[x]	0.92±0.20[x]	25.73±1.11[x]	25.77±1.12[x]	88.05±0.40[x]
66 Astax	76.31±1.38[x]	1.59±0.21[yz]	24.10±0.53[x]	24.19±0.55[x]	86.19±0.51[x]
100 Astax	75.70±0.31[x]	1.78±0.20[y]	25.21±0.80[x]	25.31±0.79[x]	85.96±0.56[x]
50 Lyco	77.47±0.81[x]	1.30±0.18[xy]	23.77±0.82[x]	23.83±0.83[x]	86.89±0.41[x]
100 Lyco	75.68±0.49[x]	1.21±0.15[xz]	23.70±0.85[x]	23.76±0.85[x]	87.09±0.33[x]
	P=0.6682	P=0.0366	P=0.3526	P=0.3562	P=0.2860

[1] Data are means ± SE of five replicate groups consisting of ten individual goldfish.
Diet descriptors indicate the concentration of pigment (mg/kg)in the diets followed by the type of pigment. Means with different superscripts in each column indicate significant differences among dietary treatments as determined by Fishers least significant difference test ($P \leq 0.05$).

5.1.2. Special diets: larvae in outdoor systems

Commercial minnow meal containing 48-50% protein is applied to ponds containing newly hatched larvae. Growth and survival of newly hatched golden shiner (1 mg) up to the small juvenile stage (0.6 g) in fertilized ponds is affected by diet, but performance of larvae fed prepared diets differing in protein composition has not been compared under simulated commercial conditions. Animal protein is presumably needed in diets of newly hatched larvae, but this has not been documented scientifically. Larvae stocked into fertilized ponds consume natural foods and a less expensive diet with only plant proteins may be sufficient for good performance. Therefore, we determined growth, survival, feed conversion, total yield, condition, and response to low dissolved oxygen of golden shiner larvae in ponds fed 36%-protein practical diets with protein from animal and plant sources, or only plant sources (Lochmann et al., 2004). Newly hatched larvae were stocked at 2,500,000/ha in twelve 0.04-ha fertilized ponds. Fish in six ponds per diet were fed twice daily at a rate of 8.0-15.9 kg/ha for 12 weeks. Chlorophyll a was not different in ponds with fish fed different diets, indicating that natural food production was similar between treatments. There were no differences in average individual weight (0.56-0.59 g)(Figure 4), relative weight (114.4-115.6), Fulton's K condition index (0.88), total yield (40.8-45.6 kg), feed conversion (0.85-0.95) or survival (75.9-79.2%) between treatments. Post-harvest survival of fish exposed to low dissolved oxygen at 20°C in a laboratory test was not affected by diet. Results indicate that diets with all plant-protein sources are suitable for raising golden shiner from first-feeding larvae to small juveniles in fertilized ponds.

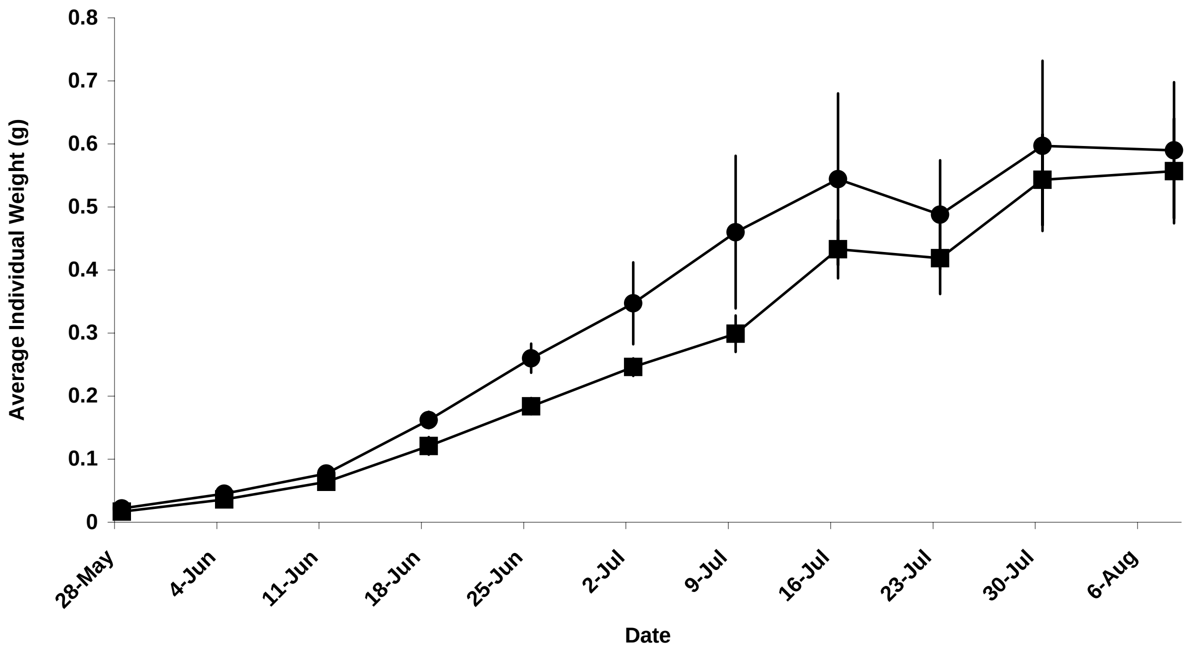


Figure 4. Growth of golden shiner fry fed a commercial diet (●) or a diet with all-plant proteins (■) in ponds.

5.1.3. Special diets: broodstock

On commercial farms baitfish broodstock receive the same diet as fish during growout, or one higher in protein (36%). The number, size, and quality of eggs and fry of other fish species (including carp) are known to be affected by the nutrient status of the mother. Some of the nutrients that are important for successful reproduction in other fish species are essential amino acids, essential fatty acids (20- and 22-carbon fatty acids of the n-3 and n-6 families), vitamins (C and E), and carotenoids. Broodstock nutrition studies have been conducted with golden shiner and fathead minnow at UAPB.

Golden shiner and fathead minnow brrodstock were fed practical diets with different lipid sources (soybean oil, cod liver oil, soybean lecithin, or mixtures of these) in outdoor pools for two months prior to spawning. The fatty acid profile of the eggs resembled those of the diets (Table 10), confirming that two months of feeding a specialized diet is enough to alter the fatty acid composition of the eggs significantly (R. Lochmann, unpublished data). Furthermore, the fish were clearly capable of elongating and desaturating 18:3n-3 and 18:2n-6 to n-3 and n-6 HUFA, respectively. However, differences in fatty acid composition of the eggs did not result in differences in egg size, total number of eggs produced, or the resistance of fry to elevated pH.

Rebecca Lochmann and Harold Phillips. 2006. Bait and Ornamental Fish Nutrition. En: Editores: L. Elizabeth Cruz Suárez, Denis Ricque Marie, Mireya Tapia Salazar, Martha G. Nieto López, David A. Villarreal Cavazos, Ana C. Puello Cruz y Armando García Ortega. Avances en Nutrición Acuícola VIII .VIII Simposium Internacional de Nutrición Acuícola. 15 - 17 Noviembre.
Universidad Autónoma de Nuevo León, Monterrey, Nuevo León, México. ISBN 970-694-333-5.

Table 10. Select fatty acid composition of eggs (% of total fatty acids by weight) of fathead minnow (FHM) and golden shiner (GS) fed diets with different lipid sources.

Fatty acid	Species	10% SBO[2]	10% CLO[2]	5% SBO +5% CLO	5% LEC[2] +5% CLO
18:2n-6	**FHM**	**8.8±0.3^{a}**	**3.3±0.1^{c}**	**6.8±0.1^{b}**	**8.4±0.3^{a}**
	GS	10.6±1.2	8.3±1.1	8.4±0.3	9.9±0.4
18:3n-3	**FHM**	**0.8±0.1**	**0.6±0.0**	**0.9±0.2**	**1.4±0.5**
	GS	1.6±0.2	2.0±0.5	1.5±0.2	1.6±0.2
20:4n-6	**FHM**	**7.9±0.1^{a}**	**3.3 ±0.3^{c}**	**4.4±0.1^{b}**	**7.9±0.3^{a}**
	GS	4.9±0.5^{AB}	3.6±0.2^{C}	3.8±0.2^{AC}	5.0±0.4^{B}
20:5n-3	**FHM**	**1.9±0.2^{c}**	**5.6±0.3^{a}**	**4.2±0.2^{b}**	**1.9+0.2^{c}**
	GS	2.8±0.4	4.2±0.9	3.8±0.1	2.3±0.2
22:6n-3	**FHM**	**14.9±0.3^{c}**	**24.9±0.4^{a}**	**22.1±0.3^{b}**	**16.0±0.7^{c}**
	GS	13.7±2.2	14.3±3.2	17.4±1.3	11.7±1.1
n-3/n-6 ratio[3]	**FHM**	**0.8±0.0^{c}**	**4.0±0.4^{a}**	**1.9±0.1^{b}**	**0.9±0.1^{c}**
	GS	1.0±0.1	1.8±0.5	1.7±0.1	1.0±0.1

[1]Values are means ± SEM of composite egg samples from 2-3 pools per treatment. Means within rows with different superscript letters are different ($P \leq 0.05$). Data for FHM are in bold to enhance distinction from GS data.
[2]Abbreviations are: SBO = soybean oil; CLO = cod liver oil; LEC = soybean lecithin.
[3] Total n-3 fatty acids included 18:3n-3, 20:5n-3 and 22:6n-3. Total n-6 fatty acids included 18:2n-6, 20:3n-6 and 20:4n-6.

In a subsequent study, fathead minnow broodstock in outdoor pools were fed practical diets containing 10% lipid as poultry fat (n-6 fatty acid source) or menhaden fish oil (n-3 fatty acid source) in combination with animal proteins (poultry + fish meals) or plant proteins. Fish received the diets for 2 months prior to spawning, which began in late February. Egg diameter, hatching percentage, larval length and larval stress tolerance (exposure to elevated pH) were determined during the spawning season (7 sampling periods). Diet had no clear effect on egg number, hatching percentage, or larval length. The results of the pH stress tests were highly variable and there were no consistent diet effects. Poultry fat and vegetable proteins appear to be suitable feed ingredients for broodstock diets of fathead minnow, as there was no increase in the quantity and quality of eggs and fry from fish fed diets with animal proteins or marine fish oil. Poultry fat and many vegetable proteins are less expensive than marine fish meals and oils, which will reduce diet cost and improve the profitability of fathead minnow production.

6. Summary

Considerable information on the nutrient requirements and practical diet development has accrued for small cyprinid fishes (golden shiner, goldfish, and fathead minnow) used as bait, “feeder” fish, or ornamentals. Most of the research has focused on macronutrients, but vitamin research has begun, and mineral nutrition is an exciting area for future research. So far, there is little evidence that nutrient requirements differ among these three species, although the majority of research in this lab has focused on golden shiner due to its dominance as a bait species. Aside from actual nutrients, there is potential to enhance performance of these fish through feed additives such as prebiotics and probiotics. Diets that increase resistance to handling and other sources of stress is potentially more significant for production and marketing of these fish than diets that maximize growth. Multiple approaches are needed to study nutrition in bait and ornamental fishes, as some of them spend most of their lives in ponds with access to live as well as prepared foods, while others are confined to aquaria where they are totally dependent on prepared diets. The nutritional and economic considerations are different in these scenarios, and diets must be continually developed and refined to address these diverse needs.

Literature Cited

Chen R., Lochmann R, Goodwin A., Praveen K., Dabrowski K., and Lee K.-J. (2003) Alternative complement activity and resistance to heat stress in golden shiners (*Notemigonus crysoleucas*) are increased by dietary vitamin C levels in excess of requirements for prevention of deficiency signs. *Journal of Nutrition* **133**, 2281-2286.

Chen R., Lochmann R, Goodwin A., Praveen K., Dabrowski K., and Lee K.-J. (2004) Effects of dietary vitamins C and E on alternative complement activity, hematology, tissue composition, vitamin concentrations and response to heat stress in juvenile golden shiner (*Notemigonus crysoleucas*). *Aquaculture* **242**, 553-569.

Davis D.A. and Gatlin D.M., III. (1996) Dietary mineral requirements of fish and marine crustaceans. *Reviews in Fisheries Science* **4**, 75-99.

Gannam A. (1992) Comparison of an all-vegetable protein diet to a commercial golden shiner diet at moderate and high stocking densities. Annual report of CSRS project ARK1437, University of Arkansas at Pine Bluff, United States Department of Agriculture.

Gatlin D.M., III. (1987) Whole-body amino acid composition and comparative aspects of amino acid nutrition of the goldfish, golden shiner and fathead minnow. *Aquaculture* **60**, 223-229.

Hertrampf J.W. (1992) *Feeding Aquatic Animals with Phospholipids II. Fishes*. Publication No.11, Lucas Meyer (GmbH and Co.), KG, Hamburg, Germany.

Lochmann R.T. and Brown R. (1997) Soybean-lecithin supplementation of practical diets for juvenile goldfish (*Carassius auratus). Journal of the American Oil Chemists' Society* **74**, 149-152.

Lochmann R. and Kumaran S. (2006) Effect of practical diets with animal or vegetable protein sources and poultry oil or menhaden fish oil on adult fathead minnow in tanks. *North American Journal of Aquaculture* **68**, 281-286.

Lochmann R.T. and Phillips H. (1994a) Dietary protein requirement of juvenile golden shiners (*Notemigonus crysoleucas*) and goldfish (*Carassius auratus*) in aquaria. *Aquaculture* **128**, 277-285.

Lochmann, R.T. and Phillips H. (1994b) Vitamin and mineral additions to golden shiners diet tested. *Arkansas Farm Research* **43**, 8-9.

Lochmann R. and Phillips H. (1996) Stable isotopic evaluation of the relative assimilation of natural and artificial foods by golden shiners *Notemigonus crysoleucas* in ponds. *Journal of the World Aquaculture Society* **27**, 168-177.

Lochmann R., Dabrowski K., Moreau R., and Phillips H. (2001) Responses of juvenile golden shiners fed semipurified or practical diets with or without supplemental ascorbic acid. *Journal of the World Aquaculture Society* **32**, 202-209.

Lochmann R. and Phillips H. (2001a) *Nutrition and feeding of baitfish.* University of Arkansas Cooperative Extension Program, University of Arkansas at Pine Bluff, United States Department of Agriculture and County Governments Cooperating. ETB # 256, AFC-01-2.

Lochmann R., and Phillips H. (2001b) Nutritional aspects of health and related components of baitfish performance. In: *Nutrition and Fish Health* (ed. By C. Lim and C. Webster), pp. 119-127. Food Products Press, Binghamton, New York, USA.

Lochmann R., Phillips H., Dasgupta S., Gatlin D., and Rawles S. (2001) Stable carbon isotope ratios and standard production data as indices of golden shiner, *Notemigonus crysoleucas,* performance in pond feeding trials.

Journal of Applied Aquaculture **11**, 21-34.

Lochmann R. and Phillips H. (2002) Nutrition and feeding of baitfish. In: *Nutrient Requirements and Feeding of Finfish for Aquaculture (ed. by* C. Lim and C. Webster), pp. 402-412. CAB International Publishers, U.K.

Lochmann R., Stone N., Phillips H. and Bodary, M. (2004) Evaluation of 36%-protein diets with or without animal protein for rearing tank-hatched golden shiner fry in ponds. *North American Journal of Aquaculture* **66**, 271-277.

NRC (National Research Council). (1993) *Nutrient Requirements of Fish*. National Academy Press, Washington, D.C., USA.

Robinson E. and Li M. (2002) Channel catfish*, Ictalurus punctatus.* In: *Nutrient Requirements and Feeding of Finfish for Aquaculture (ed. by* C. Lim and C. Webster), pp. 293-318. CAB International Publishers, U.K.

Robinson E., Li M. and Oberle D. (1998) *Catfish Vitamin Nutrition*. Bulletin 1978, Mississippi Agricultural and Forestry Experiment Station. Mississippi State, Mississippi.

Stone N., Park E., Dorman L. and Thomforde H. (1997) *Baitfish Culture in Arkansas: Golden Shiners, Goldfish, and Fathead Minnows.* Cooperative Extension Program, University of Arkansas at Pine Bluff, United States Department of Agriculture, and County Governments Cooperating.

Thyparambil S. (2004) Effect of astaxanthin or lycopene supplementation of practical diets on performance of goldfish (*Carassius auratus*) and sunshine bass (*Morone chrysops* x *M. saxatilis*). M.S. Thesis, University of Arkansas at Pine Bluff, Pine Bluff, Arkansas, USA.