ETB256

Nutrition and Feeding of Baitfish

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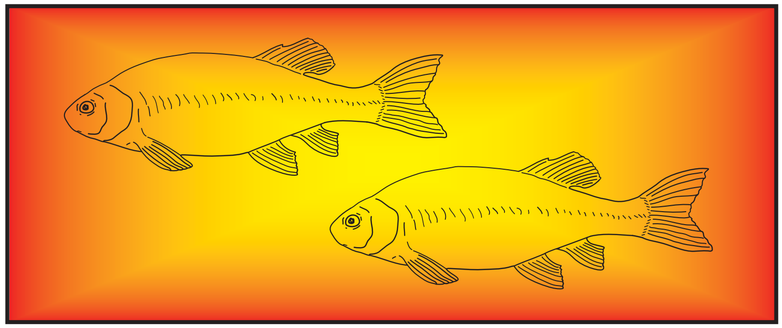

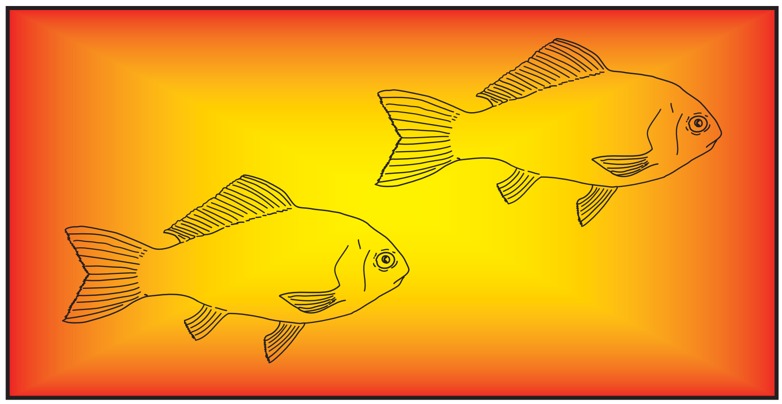

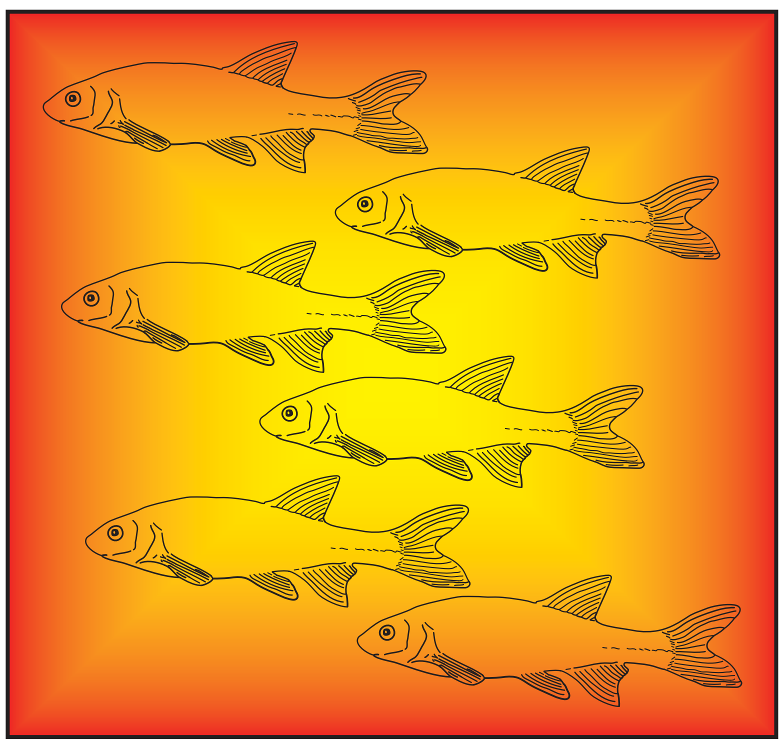

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The cover was designed by Robert Thoms and Richard Gehle.

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PREFACE

This is an updated version of manual ETB256, *Nutrition and Feeding of Baitfish*. Most of the studies included in this manual were conducted by scientists at the University of Arkansas at Pine Bluff (UAPB), but many included collaborators from other southern states. New studies covered in this manual address vitamin nutrition in golden shiner, color enhancement in goldfish, diets for fry, broodstock and "jumbos," use of non-fish sources of proteins and lipids, and dietary prebiotics.

Since the first manual was published, most of the additional studies conducted have included measures of fish health rather than just standard production data. This approach gives a more integrated picture of the effects of different diets and feeding regimes on baitfish. Baitfish must survive and remain in good condition well beyond harvest since they are marketed live. Therefore, the effects of diet on stress and immune responses have received more attention in recent research. The development of tools to assess these responses in small fish has also enhanced our knowledge of the interaction between diet and health in baitfish.

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*). 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 baitfish and channel catfish in ponds.

Factor	Baitfish[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; fat does not reduce marketability/be an advantage	Large amount of body fat reduces dressout percentage

[1]Includes golden shiners, goldfish and fathead minnows (Stone *et al.* 1997).
[2]Robinson and Li (1996).

RELATIVE IMPORTANCE OF NATURAL AND PREPARED FEEDS

Most baitfish producers encourage natural food production by using appropriate fertilization and monitoring regimes. 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.

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

Diet number	Diet $\delta^{13}C$	Mean individual weight gain (g)	Pond contribution (%)[2]
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] See Lochmann and Phillips (1996) for details.

Experiment 1

To estimate the relative contribution of natural and prepared foods to the nutrition of golden shiners, an eight-week feeding trial was conducted in 0.04-ha (0.1-acre) ponds using stable carbon isotope ratios, ($\delta^{13}C$) as nutrient tracers. 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 (0.13-in mesh) in unfertilized ponds. The stocking density was comparable to an intensive level of 220,089 fish/acre.

Three nutritionally similar diets with a range of $\delta^{13}Cs$ were prepared at UAPB. Each diet was fed to fish in one net within each of four ponds at a rate of 4 percent body weight/day divided into two feedings. The $\delta^{13}Cs$ 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 $\delta^{13}Cs$ 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 percent 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.

Experiment 2

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 in ponds was examined in simultaneous eight-week feeding trials at the University of Arkansas at Pine Bluff (UAPB) and Texas A&M University (TAMU). Ten 0.1-acre ponds per site were fertilized with defatted rice bran and stocked with golden shiners (initial individual weight =1.3-1.4 g) at a rate of 300,000 fish/acre (UAPB) or 150,000 fish/acre (TAMU). Fish in five ponds per site were fed a nutritionally complete prepared diet at 4 percent 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 (**Table 3**). 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. Minimum DO, plankton isotope ratio, and the fed/unfed variables significantly affected fish isotope ratio.

This experiment highlighted the importance of two issues: 1) feeding fish a prepared diet more than tripled growth rates at both densities; and 2) there was greater use of prepared diet by fish at the lower density, where natural productivity was also low.

Table 3. Performance of golden shiners in 0.1-acre fertilized ponds stocked at different densities. Fish in half of the ponds at each density were not fed, while fish in the remaining ponds were fed a 32%-protein diet at 4% body weight once daily for 8 weeks.[1]

Stocking density	Average individual weight increase (%)	
(fish/acre)	Unfed	Fed
150,000	94[b]	336[a]
300,000	26[b]	272[a]

[1] Performance data are means of 5 ponds each. Individual fish averaged 1.3-1.4 grams initially. Means within rows with different superscripts are significantly different ($P<0.05$) as determined by Fisher's least significant difference test.

ENERGY-YIELDING NUTRIENTS

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.

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.

Amount

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.

Experiments 1 and 2

The total dietary protein requirement and the protein:energy ratio of golden shiner and goldfish were examined in separate experiments. Juvenile golden shiners and goldfish (initial individual weight = 0.2 g) 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 percent protein was similar to that of fish fed diets with higher protein levels (up to 34 percent) when fed at 4-7 percent of body weight (**Tables 4 and 5**). The ideal dietary energy:protein ratio for growth of golden shiners and goldfish in aquaria was

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

Diet number	Dietary protein (%)	Initial group weight (g)	Weight gain (g)	Feed efficiency[2]	Protein efficiency ratio[3]	Survival (%)
1	21.2	5.3	27[c]	0.52[b]	3.3[a]	100.0
2	25.3	5.6	31[bc]	0.55[b]	3.0[b]	100.0
3	28.9	5.4	34[abc]	0.61[a]	3.3[ab]	85.7
4	31.1	5.5	39[ab]	0.64[a]	3.1[ab]	100.0
5	34.5	5.5	42[a]	0.65[a]	2.7[c]	100.0

[1]Values are means of three groups of 30 fish each. Means within columns with different superscripts are significantly different ($P<0.05$) as determined by Fisher's least significant difference test.
[2]Feed efficiency=final group weight+weight of mortalities-initial group weight in grams.
[3]Protein efficiency ratio=grams gained/grams dietary protein fed.

Table 5. Performance of juvenile goldfish fed diets differing in protein content for 6 weeks.[1]

Diet number	Dietary protein (%)	Initial group weight (g)	Weight gain (g)	Feed efficiency[2]	Protein efficiency ratio[3]	Survival (%)
1	21.2	6.0	13[c]	0.49[c]	3.1[abc]	100.0
2	25.3	6.0	15[bc]	0.53[bc]	2.9[bcd]	99.2
3	28.9	5.9	19[a]	0.61[a]	3.3[a]	100.0
4	31.1	6.0	17[ab]	0.59[ab]	2.8[bd]	98.3
5	34.5	6.0	19[a]	0.63[a]	2.6[d]	98.3

[1]Values are means of three groups of 40 fish each. Means within columns with different superscripts are significantly different ($P<0.05$) as determined by Fisher's least significant difference test.
[2]Feed efficiency=final group weight+weight of mortalities-initial group weight in grams.
[3]Protein efficiency ratio=grams gained/grams dietary protein fed.

9.7 kcal of digestible (available) energy per gram of dietary protein. Analysis of variance was used 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 UAPB indicate that 29 percent protein is a valid estimate of the minimum dietary requirement for growth of this species.

Experiment 3

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 0.1-acre ponds. Golden shiners (initial individual weight = 1.24 g) were fed diets similar in energy:protein ratios but different in total protein levels (22 or 28 percent) to satiation twice daily for 10 weeks. Weight gain of fish fed the diet with 28 percent 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 6**).

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 baitfish. 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.

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 are similar to those of channel catfish and common carp, indicating that the essential amino acid requirements are similar for these species.

Experiment 1

A feeding trial was conducted with golden shiner to address the dietary lysine requirement, as lysine is the first limiting amino acid in many practical feed ingredients. UAPB researchers used purified casein-gelatin diets and crystalline amino acids and graded levels of lysine (0.0, 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5 mg/kg diet). Fish were fed twice daily to satiation for 16 weeks, but the study was terminated due to very slow growth and the absence of deficiency signs that typically appear within a few weeks when fish are maintained on diets deficient in essential amino acids. Survival was good (94.8+0.6 percent) on all diets, but growth was so slow (178.5+5.2 percent growth increase) that no dietary effects were observed. The slow growth might be due partly to a limited ability to use crystalline amino acids. Alternative methods may be needed to determine dietary amino acid requirements in golden shiner, such as use of intact protein sources with different concentrations of essential amino acids.

In practical diets for baitfish, soybean meal is the main protein

Table 6. Performance of golden shiners in 0.1-acre ponds fed diets with different protein levels but similar energy:protein ratios for 10 weeks.[1]

Dietary protein (%)	Energy:protein ratio[2]	Mean individual weight gain (g)	Total yield (lbs/acre)	Feed conversion
22	11.5	3.5	754	2.5
28	11.2	3.9	635	3.1

[1]Performance data are means of four ponds each stocked at a rate of approximately 375,000 fish/acre. 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.

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 Dr. Ann Gannam, regional nutritionist, head of Applied Nutrition Research Program, USFWS, Abernathy Fish Technology Center, 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 percent fish meal. The primary vegetable protein source for all diets was soybean meal.

Experiment 2

The relative quality of different protein sources was compared in a seven-week feeding trial with practical diets fed to golden shiners (initial individual weight = 0.2 g) in aquaria. 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 7**). Concurrent feeding trials were conducted in indoor aquaria and outdoor pools to determine the effects of a diet with 5 percent fish meal or a diet without fish meal on growth, survival, feed efficiency and condition index of golden shiners. A combination of feed-grade poultry by-product meal and soybean meal supplied most of the protein in the diet without fish meal. Fish were fed to satiation twice daily for 10 weeks (pools) or 14 weeks (aquaria). There were no differences in performance of golden shiners fed diets with or without fish meal in aquaria (without access to natural foods) or pools (with access to natural foods). The combined results of aquarium, pool and pond trials indicate that animal protein sources are not critical in practical diets for growth of golden shiners.

Lipids (Fats)

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. 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 baitfish, where increases in body fat associated with consumption of high-fat diets does not usually reduce market value.

Amount
Experiments 1 and 2

The optimal dietary lipid level for juvenile golden shiners and goldfish was determined in a series of experiments. In separate feeding trials, golden shiners and goldfish in aquaria were fed purified diets with graded levels of a mixture (50/50 percent) of cod liver and soybean oils. The lipid mixture contained fatty acids of the n-3 and n-6 families that meet the EFA requirements of most fish species. Weight gain of golden

Table 7. Performance of juvenile golden shiners fed diets differing in protein source for 8 weeks.[1]

Protein variable (%)	Mean individual 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 three groups of 30 fish each. Means within columns with different superscript letters are significantly different (P<0.05) as determined by Fisher's least significant difference test.

shiners fed diets containing 34 percent protein and 7-12 percent lipid was higher than that of fish fed diets with lower or higher lipid levels (**Table 8**).

Survival of golden shiners fed diets with 4.6-14.8 percent lipid in aquaria was 92 percent 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 percent (**Table 9**).

The highest lipid level (13.3 percent) significantly reduced weight gain relative to fish fed diets with 7.1 percent lipid or less. The highest lipid level (13.3 percent) significantly reduced feed efficiency relative to fish fed diets with 8.9 percent lipid or less. Survival increased with dietary lipid level but was 93 percent or higher in all treatments.

Experiment 3

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

Experiment 4

Golden shiners (initial individual weight = 0.9 g) in ponds (0.1-acre) stocked at 686 lb/acre were fed supplemental practical diets containing 4 or 13 percent poultry fat or 13 percent menhaden fish oil to satiation twice daily for twelve weeks. Weight gain of golden shiners fed the diet with 4 percent poultry fat was higher than that of fish fed either diet with 13 percent lipid (**Table 10**). 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 percent lipid. Whole-body lipid of the golden shiners fed the diet with 13 percent menhaden fish oil was higher than that of fish fed the diets with 4 or 13 percent poultry fat. This implies a difference in metabolism of poultry and fish oils by golden shiners, which needs further study.

Experiment 5

Goldfish (initial individual weight = 0.9 g) stocked at 600 fish per fertilized pool (1,069 gal) were fed practical diets containing 4 or 13 percent lipid as poultry fat or menhaden fish oil at 3-6 percent BW for nine weeks. These supplemental diets contained 24 percent

Table 8. Performance of juvenile golden shiners fed diets with different lipid levels for 9 weeks.[1,2]

Diet number	Dietary lipid (%)	Mean individual initial weight (g)	Mean individual weight gain (g)	Feed efficiency	Survival (%)
1	4.6	0.22	0.89[b]	0.69	98.3[ab]
2	7.1	0.22	0.97[ab]	0.74	98.3[ab]
3	11.2	0.23	1.00[a]	0.75	100.0[a]
4	12.1	0.21	1.03[a]	0.76	91.7[b]
5	14.8	0.22	0.88[b]	0.68	97.7[ab]

[1]Values represent means of three groups of 20 fish per group.
[2]Means with different superscripts are significantly different ($P<0.05$) as determined by Fisher's least significant difference test.

Table 9. Performance of juvenile goldfish fed diets with different lipid levels for 9 weeks.[1,2]

Diet number	Dietary lipid (%)	Mean individual initial weight (g)	Mean individual weight gain (g)	Feed efficiency	Survival (%)
1	4.5	0.47	2.9[a]	0.80[a]	93.3[b]
2	7.1	0.47	2.7[a]	0.79[a]	97.3[a]
3	8.9	0.47	2.4[ab]	0.75[a]	97.3[a]
4	10.3	0.46	2.4[ab]	0.74[ab]	97.3[a]
5	13.3[b]	0.46	1.9[b]	0.68[b]	100.0[a]

[1]Values represent means of three groups of 25 fish per group.
[2]Means with different superscripts are significantly different ($P<0.06$) as determined by Fisher's least significant difference test.

Table 10. Performance of golden shiners in 0.1-acre ponds fed diets differing in lipid source and amount for 12 weeks.[1]

Lipid Amount (%)	Lipid source	Mean individual weight gain (g)	Net yield (lbs/acre)	Feed conversion	Whole-body lipid (%)
4	Poultry fat	6.3[a]	485	5.5	11.4*
13	Poultry fat	5.3[b]	595	2.9	10.6*
13	Menhaden fish oil	5.2[b]	529	3.7	14.3**

[1]Values are means of four ponds each stocked at a rate of 925,000 fish/ha (370,000 fish/acre). Individual fish weighed 0.9 grams initially. Means within columns with different superscript letters are significantly different at P<0.05. Means within columns with different numbers of asterisks are significantly different at P<0.10. Differences were determined by Fisher's least significant difference test.

Table 11. Mean condition index and whole-body protein and dry matter of golden shiners fed diets with 4 or 10% poultry fat (PF) in pools for 10 weeks.[1]

Diet	Condition index (g)[2]	Whole-body protein (%)	Whole-body dry matter (%)
Aquaria			
Basal – 4% PF	1.00	5.7[x]	80.0
Basal – 10% PF	1.06	5.8[x]	88.0
Pools			
Basal – 4% PF	1.00	5.7[x]	80.0
Basal – 10% PF	1.06	5.8[x]	88.0

[1]Means within columns with different superscript letters are significantly different (P<0.10) as determined by Fisher's least significant difference test.
[2]Fulton's K = (weight/length^3) x 100, where weight is in grams and length is total length (cm).

Table 12. Results of studies in aquaria and pools with golden shiners fed diets with 4% or 10% poultry fat (PF).

Parameter	Aquaria	Pools
Weight gain and feed conversion	4% PF = 10% PF	4% PF = 10% PF
Survival	10% PF > 4% PF	4% PF = 10% PF
Condition factor	not measured	10% PF > 4% PF
Whole-body lipid and dry matter	4% PF = 10% PF	10% PF > 4% PF
Whole-body protein and ash	4% PF = 10% PF	4% PF = 10% PF

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 percent lipid, compared to fish fed diets with 4 percent lipid (**Table 11**). 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 percent 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.

Experiments 6 (Aquaria) and 7 (Outdoor Pools)

Concurrent feeding trials were conducted in indoor aquaria (29 gal) and outdoor pools (1,069 gal) to determine the effects of diets with 4 or 10 percent added lipid (poultry fat = PF) on performance of golden shiners. Initial individual weights of fish were 1.4 g and 0.46 g for the aquarium and pool trials, respectively. Fish were fed to satiation twice daily for 10 weeks (pools) or 14 weeks (aquaria). There were no differences in weight gain, feed conversion ratio or whole-body protein or ash between fish fed diets with 4 percent or 10 percent PF in aquaria or pools (**Table 12**).

In aquaria, survival of fish fed the diets with 10 percent PF was higher than that of fish fed the diets with 4 percent PF. In pools, condition factor, whole-body lipid and whole-body dry matter were higher in golden shiners fed diets with 10 percent PF versus 4 percent PF. Differences in results between aquaria and pools are due partly to the higher growth rate in pools and the presence of natural foods.

Experiments 8 (Aquaria) and 9 (Pools)

Two feeding trials were performed with goldfish in aquaria or pools to determine the effects of diet with 4 or 10 percent added lipid and 0 or 2 percent dairy/yeast prebiotic. These trials were conducted to determine whether a combination of extra lipid and prebiotic might enhance fish performance more than either supplement alone. In aquaria, there were no differences in weight gain or survival among diets. In contrast, goldfish in pools fed the high-lipid diets with or without the prebiotic had better weight gain and higher condition index than fish fed the 4 percent lipid diet without prebiotic (prebiotic effects are discussed later under "feed additives").

Clearly, higher levels of dietary lipids provide some benefits for baitfish. Most notably, survival and whole-body lipid were enhanced by high-fat diets, which might improve the ability of the fish to handle stress and periods of fasting, such as during transport and retail display. Because higher levels of lipid increase diet cost, economic analysis is needed to determine whether addition of extra lipid to commercial diets is justified.

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 that originate from algae. These fatty acids are required in the diet of 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., eicosanoids) 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 13**.

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

Table 13. Summary of studies at UAPB to determine the types of fatty acids needed by golden shiners.[1,2]

Study length/ Initial weight	Lipid sources	Main results[3]
9 wks/ 0.21 g	soybean, rice bran, canola, cod liver, poultry	No differences in WG or SURV by diet; whole-body lipid was higher in fish fed plant 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/ 0.35 g	soybean, canola, cod liver, soy+cod liver (50/50%), olive FA	WG of fish fed the SBO+CLO, olive, and SBO diets was highest; no differences in SURV; 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: R. Lochmann and H. 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

Table 14. Performance of juvenile goldfish fed practical diets supplemented with soy lecithin (LEC), soybean oil (SBO) and/or cod liver oil (CLO) for 6 weeks.[1]

Dietary lipid supplement (%)	Initial group weight (g)	Weight gain (g)	Feed efficiency[2]	Survival (%)	Whole-body lipid (%)
CLO (4%)	12.0	19.9[c]	0.45[b]	98.3	19.5
CLO (2%) + LEC (2%)	11.9	23.1[ab]	0.51[a]	100.0	22.0
SBO (4%)	11.9	22.1[bc]	0.50[ab]	98.3	23.1
SBO (2%) + LEC (2%)	11.9	23.1[ab]	0.51[a]	100.0	24.8
LEC (4%)	11.9	25.2[a]	0.55[a]	100.0	21.2

[1]Values are means of three groups of 40 fish each. Means within columns with different superscripts are significantly different ($P<0.05$) as determined by Fisher's least significant difference test.
[2]Feed efficiency=final group weight+weight of mortalities-initial group weight in grams.

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. Eicosanoids 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 percent 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

Table 15. Weight gain, condition index and survival of fathead minnow fed diets with or without animal protein sources and different lipid sources for 5 months.[1]

Diet	Individual fish weight gain (g)[2]	Condition Index (Fulton's K)[3] Males	Condition Index (Fulton's K)[3] Females	Survival (%)
Anim-PO[4]	0.48	1.07	1.03	78.5
Anim-MFO	0.43	1.11	1.02	85.5
Veg-PO	0.39	1.06	0.98	86.4
Veg-MFO	0.46	1.06	1.00	84.0
Two-way ANOVA				
P (Protein source)	0.61	0.12	0.01	0.17
P (Lipid source)	0.90	0.17	0.77	0.32
P (Protein x Lipid)	0.31	0.25	0.40	0.05

[1]Values are means of six replicate tanks per diet. P-values are shown in parentheses below each pair of means. Means within columns were not significantly different ($p>0.10$).
[2]Weight gain=final average individual weight-initial average individual weight.
[3]Fulton's K = (weight/length^3) x100, where weight is in grams and length is total length (cm).
[4]Abbreviations are: Anim, animal protein; Veg, vegetable protein; PO, poultry oil; MFO, menhaden fish oil; ANOVA, analysis of variance.

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 (**Table 14**). Phospholipids may improve lipid digestion, absorption and transport in baitfish, as in other fish.

Interactions Between Proteins and Lipids

Researchers measured growth, survival, feed conversion and response to low dissolved oxygen of adult fathead minnow in aquaria 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. Good weight gain (0.6-0.8 g) was obtained either with vegetable-protein or animal-protein sources (**Table 15**). 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 percent and 96 percent, respectively, and was not affected by lipid source. Survival during the low-oxygen stress test was high (≥90 percent) across diets, but survival was lower in fish fed the animal-protein diet with poultry oil than the animal-protein diet with menhaden fish oil. Vegetable proteins and poultry oil are promising alternatives to more costly diet ingredients in practical diets for fathead minnow.

Table 16. Performance of juvenile golden shiners fed diets[1] with different lipid and starch content for 8 weeks.[2]

Dietary starch source (amount)	Dietary lipid[3] (%)	Mean individual weight gain (g)	Feed efficiency	Survival (%)
Corn (15%)	15.0	0.89	0.70	97.0
Corn (30%)	8.3	0.84	0.68	99.0
Corn (45%)	1.7	0.89	0.70	98.0
Rice (15%)	15.0	0.94	0.73	99.0
Rice (30%)	8.3	0.84	0.66	98.0
Rice (45%)	1.7	0.88	0.70	98.0

[1]Diets were formulated to contain equal amounts of protein and total energy.
[2]Values represent means of three groups of 30 fish per group. Initial individual fish weight was 0.2 grams. Means were not significantly different (P>0.05).
[3]The lipid source for all diets was a 50/50% mixture of menhaden fish oil and soybean oil.

Table 17. Performance of juvenile golden shiners fed diets with 15% soluble carbohydrate from different sources for 8 weeks.[1,2]

Dietary carbohydrate source	Initial individual weight (g)	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 least significant difference test.

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.

Amount

Weight gain and survival of golden shiners fed laboratory (semi-purified) diets differing in starch content (15, 30 or 45 percent) and lipid (15, 8.3 or 1.7 percent) was similar (**Table 16**), indicating that they perform well over a wide range of dietary carbohydrate:lipid ratios (1:1 to 27:1). 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.

Source

In another experiment, weight gain of golden shiners fed dietswith 15 percent carbohydrate from different sources improved with increasing complexity of the carbohydrate: starch> dextrin>sucrose=glucose (**Table 17**). 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.

VITAMINS AND MINERALS

Micronutrients include vitamins and minerals. 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 fry reportedly can absorb some vitamins directly from the water, but natural foods rich in vitamins are also heavily consumed by baitfish fry. 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.

The criteria used to assess vitamin and mineral requirements should include indices of health, such as stress and immune responses. Early studies with baitfish did not include health indices, but vitamins and minerals such as vitamin C (ascorbic acid) and zinc have prominent roles in maintaining health. It is important to measure a wide range of performance variables in baitfish during and after production using conditions that simulate commercial scenarios as much as possible.

Vitamin-Mineral Supplement

Weight gain and total net yield of golden shiners in 0.1-acre ponds fed diets with or without a combination vitamin and mineral supplement (**Table 18**) for eight weeks did not differ (**Table 19**). 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

Table 18. Composition of the basal diet and vitamin/mineral supplement used in a pond study with golden shiners to determine whether supplemental vitamins and minerals are required for good production.[1]

Diet ingredients	(%)
Soybean meal	41.0
Cottonseed meal	10.0
Menhaden fish meal	5.0
Yellow corn	15.0
Wheat (hard red)	15.0
Wheat midds	14.0 or 10.6
Vitamin C (Stay-C)[2]	2 0.0 or 0.05
Vitamin/mineral premix	0.0 or 3.0
Vitamin/mineral premix ingredients	**Amount**
Copper	0.68 g/lb
Iron	5.44 g/lb
Manganese	16.33 g/lb
Zinc	15.65 g/lb
Cobalt	0.14 g/lb
Iodine	0.34 g/lb
Choline	40.68 g/lb
Folic acid	200.00 mg/lb
Niacin	8.00 g/lb
Pantothenic acid	3.20 g/lb
Riboflavin	1.20 g/lb
Thiamin	1.00 g/lb
Vitamin B_{12}	800.00 µg/lb
Vitamin E	5.00 KIU/lb
Vitamin K	227.50 mg/lb
Vitamin A	0.40 MIU/lb
Vitamin D_3	0.20 MIU/lb

[1]Diets were extruded as 3⁄32-inch floating pellets containing 32% protein.
[2]Stay-C is a stabilized form of vitamin C produced previously by Roche Vitamins, Ltd.

Table 19. Performance of golden shiners in 0.1-acre ponds fed diets with or without a vitamin/mineral supplement for 8 weeks.[1]

Diet[2]	Mean group weight gain (lbs)	Net yield (lbs/acre)	Feed conversion	Survival (%)
Unsupplemented	93.0	789.6	1.9	81.6
Supplemented	104.4	790.4	1.8	68.7

[1]Values are means of four ponds, each stocked at a rate of 300 lb/acre. 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 and 0.05% of stabilized vitamin C.

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.

Vitamin C

Experiment 1

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 (initial individual weight = 0.5 g). Diets with casein (milk protein) or fish meal and either 0 or 250 mg/kg (ppm) 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 (**Table 20**). 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. It was concluded that the dietary vitamin C requirement for golden shiner is influenced by diet composition and health status.

Experiment 2

Researchers 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 weeks. Weight gain, survival and gross deformities were assessed at 10 weeks. The remaining fish were maintained on the same diets from weeks 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 established in fish fed 0 mg AA/kg diet for 10 weeks (**Figure 1**).

Table 20. Weight gain, feed efficiency and instantaneous mortality of golden shiner fed casein- or fish-meal based diets containing 0 or 250 mg of ascorbic acid (AA)/kg diet for twelve weeks.[1,2]

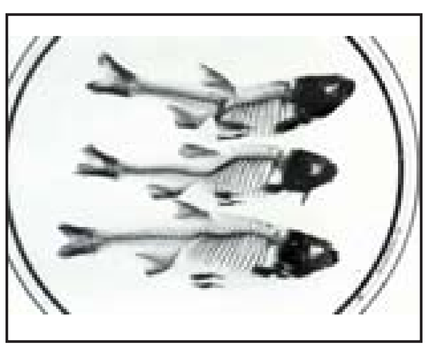
Diet type (AA level)	Weight gain (g)	Feed efficiency	Instantaneous mortality T=1	Instantaneous mortality T=2
Casein-no AA	2.97	0.58	0.31	0.71 **
Casein-250 AA	2.84	0.61	0.12	0.09 *
Fish meal-no AA	2.47a	0.64	0.10	0.00
Fish meal-250 AA	3.06b	0.67	0.12	0.04

[1]Values for weight gain, feed efficiency and instantaneous mortality (T=1) are means of three replicates (tanks). Each tank contained a group of 30 fish initially. The number of individuals per replicate used to calculate instantaneous mortality (T=2) varied due to differential mortality during T=1.

[2]Treatment means were compared using an unpaired t-test. Means within columns followed by different letters or numbers of asterisks were significantly different at P<0.05 and P<0.06, respectively

A

C



B

Figure 1. Golden shiners exhibiting: A. Lateral spinal curvature (scoliosis); B. Fractures of the vertebral column; C. Dorsoventral spinal curvature (lordosis); after consuming a diet with no vitamin C for 10 weeks.

A 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 after exposure to elevated temperature (°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.

Interactions Between Vitamins C and E

UAPB researchers characterized the response of golden shiner fed one of eight purified diets with either 0 or 38 mg α-tocopherol (vitamin E)/kg diet, and one of four levels of ascorbic acid (AA) (23, 43, 98 or 222 mg/kg diet) in a 2 X 4 factorial design. Growth, survival, signs of vitamin-E deficiency and immune and stress responses were monitored in groups of 30 golden shiners (initial individual weight = 0.79 g) 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 vitamin E concentrations at 14 weeks, but the survival of fish fed the diets with no added vitamin E was lower than that of fish fed the diets with added vitamin E. After 10 weeks, fish fed the diets without added vitamin E began to show vitamin E-deficiency signs such as increased prevalence of fish with darkened skin, muscular atrophy and hemorrhaging in the skin (**Figure 2**).

Figure 2. Golden shiners exhibiting: A. Muscular atrophy and skin darkening; B, Abnormal pigmentation and disorientation, after consuming a diet with no added vitamin E for 10 weeks.

After 17 weeks the deficient fish had lower vitamin E concentrations in viscera, lower whole-body crude protein, total lipid, dry matter, hematocrit, hemoglobin, lymphocyte (percent), alternative complement activity (ACH50) and survival after exposure to stressful water temperatures (36-37°C) than those fed the diets with added vitamin E. 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 (platelets) was also significant. Regardless of vitamin E levels, different vitamin C levels did not influence the concentration of vitamin E in viscera and other interactions between vitamins C and E were not evident.

Additional Needs – Minerals

Minerals are inorganic substances required in small amounts for normal growth, health and function. Mineral nutrition of baitfish has not been addressed in the UAPB lab. Presumably, it is similar to that of other cyprinid fishes. The mineral content of practical diets is based on requirements for channel catfish, 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.

Additional basic studies to determine both mineral and vitamin requirements of different species of bait and ornamental fish for growth, survival, optimal health, stress response 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. For instance, the highest tissue concentrations of vitamin C that UAPB researchers have observed were in golden shiners in ponds fed a diet that contained 50 mg vitamin C/kg diet for seven weeks. Golden shiners in aquaria required more than 200 mg vitamin C/kg diet for 10 weeks to accumulate about 78 percent of the amount of vitamin C that was obtained in the pond-reared fish. Clearly, fish in ponds can acquire substantial amounts of vitamin C from natural foods. However, natural foods vary in quality and quantity and may not always supply enough vitamin C to meet the nutrient requirements of baitfish.

FEEDING PRACTICES

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 percent protein, solvent-extracted) is the primary protein source in commercial baitfish feeds, and very little (2-5 percent) fish meal is used in diets for juveniles and adults. There is no research supporting benefits of fish meal in baitfish beyond that of other, less expensive protein sources. In addition, 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 (10-13 percent) diets have generated some interest among baitfish producers. The cost of increased dietary lipid may be offset by increased survival and hardiness of the fish during transport and retail display, but the economics will depend 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 percent protein and 5 percent added fat (as soybean oil and/or poultry fat) should support weight gain and fish health during growout.

Some phases of baitfish production and marketing are more stressful than others, and baitfish may benefit from diets with modified levels of vitamins, minerals or other nutrients given for a short period prior to events such as grading or transport. In one study, there was no difference in the stress response to crowding of golden shiners fed diets with different lipids. However, the feeding period was short (four weeks) and the results (cortisol data) were highly variable due to the difficulty of measuring cortisol in very small fish. Progress in this area of research will be facilitated by a whole-body cortisol assay that was developed in UAPB's lab. This procedure allows the measurement of stress responses in small baitfish fed diets with different ingredients. One study using this technique showed that bar grading was the most stressful event that baitfish encounter routinely. The same study showed that tissue levels of ascorbic acid and zinc did not decline during potentially stressful activities such as harvesting, grading and ground or air transport. Ascorbic acid and zinc are both key nutrients in the immune response, which is linked to the stress response, and exposure to severe or prolonged stress might be expected to deplete these nutrients in the tissues. There is still a need to conduct research with known diet formulations to establish the specific effects of vitamins and minerals on the stress and immune responses of baitfish during production and post-production processes.

Feeding strategies for baitfish change seasonally, although diet composition generally does not. Survival improves and condition of golden shiners during winter is maintained by feeding at a rate of 1-2 percent body weight at afternoon air temperature of > 45°F (7°C). Increased numbers of fathead minnows in good condition in ponds can be achieved with a feeding rate of 3 percent body weight per day (using a 32 percent protein feed) from late summer to winter. In summer, many producers reduce feeding rates when water temperatures exceed 86°F (30°C).

Fry Diets

Commercial minnow meal containing 48-50 percent 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 fry, but this has not been documented scientifically. Fry stocked into fertilized ponds consume natural foods, and a less expensive diet with only plant proteins may be sufficient for good performance. Therefore, researchers determined growth, survival, feed conversion, total yield, condition and response to low dissolved oxygen of golden shiner larvae in ponds where the larvae were fed 36 percent protein practical diets with protein from animal and plant sources, or only plant sources. Newly hatched fry were stocked at 1,000,000/acre in twelve 0.1-acre fertilized ponds. Fish in six ponds per diet were fed twice daily at a rate of 7-14 lb/acre 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, relative weight, Fulton's K condition index, total yield, feed conversion or survival between treatments (**Table 21**). Post-harvest survival of fish exposed to low dissolved oxygen at 68°F (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.

Broodstock Diets

On commercial farms, baitfish broodstock receive the same diet as fish during growout, or one higher in protein (36 percent). The number, size and quality of eggs and fry of other fish species (including carp) are 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

Table 21. Production parameters for golden shiner fry in 0.1-acre ponds fed a commercial diet or a diet with all-plant proteins for 12 weeks.[1,2]

Diet	Mean individual final weight (g)[3]	Relative weight[4]	Condition index[5]	Total yield[6] (lbs/acre)	Feed conversion[7]	Survival (%)
Commercial	0.59	114.4	0.88	1,006	0.85	79.2
All-plant proteins	0.56	115.6	0.88	900	0.95	75.3

[1]Values are means of 5-6 replicate ponds per diet.
[2]Treatment means within columns were not significantly different ($P<0.10$) as determined by a 1-way ANOVA test.
[3]Individual fry weighed approximately 0.001g initially. Weight gain=final average individual weight-initial average individual weight.
[4]Relative weight (Wr)=[weight(g)/Ws] x 100; where $\log_{10} W_s = -5.593 + 3.302 \log_{10} TL$ (mm).
[5]Fulton's K= [weight(g)/length(cm)^3] x 100.
[6]Total weight of fish harvested from each pond.
[7]Feed conversion=feed fed/total weight.

Table 22. 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.[1]

Fatty acid	Species	10% SBO[2]	10% CLO[2]	5% SBO +5% CLO	5% LEC[2] +5% CLO
18:2n-6	**FHM**	**8.8[a]**	**3.3[c]**	**6.8[b]**	**8.4[a]**
	GS	10.6	8.3	8.4	9.9
18:3n-3	**FHM**	**0.8**	**0.6**	**0.9**	**1.4**
	GS	1.6	2.0	1.5	1.6
20:4n-6	**FHM**	**7.9[a]**	**3.3[c]**	**4.4[b]**	**7.9[a]**
	GS	4.9[AB]	3.6[C]	3.8A[C]	5.0[B]
20:5n-3	**FHM**	**1.9c**	**5.6a**	**4.2b**	**1.9[c]**
	GS	2.8	4.2	3.8	2.3
22:6n-3	**FHM**	**14.9[c]**	**24.9[a]**	**22.1[b]**	**16.0[c]**
	GS	13.7	14.3	17.4	11.7
n-3/n-6 ratio[3]	**FHM**	**0.8**	**4.0[a]**	**1.9[b]**	**0.9[c]**
	GS	1.0	1.8	1.7	1.0

[1]Values are means of composite egg samples from two to three pools per treatment. Means within rows with different superscript letters are different ($P<0.05$). 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.

n-6 families), vitamins (C and E) and carotenoids. Broodstock nutrition studies have been conducted with golden shiner and fathead minnow at UAPB.

Experiment 1
To guide diet development, the chemical and physical characteristics of golden shiner eggs were measured over time during a spawning season. The broodstock were fed a nutrient-dense diet with 40 percent protein and 9 percent fat so that nutrition would not be a limiting factor. Although egg volume declined over time, the lipid and amino acid components of the eggs were stable, indicating that normal embryological development was possible throughout the spawning season.

Experiment 2 and 3
Additional trials were conducted to determine the specific relationship between diet composition, chemical composition of the egg and egg and fry quality. Golden shiner and fathead minnow broodstock 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 22**), confirming that two months of feeding a specialized diet is enough to alter the fatty acid composition of the eggs significantly. 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.

Experiment 4
In a subsequent trial, fathead minnow broodstock in outdoor pools were fed practical diets containing 10 percent 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 two 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 (seven 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 measurable 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.

Production of "Jumbos"

There is a good market for large golden shiners used as bait for sportfishing, but they are difficult to produce in one year. Dr. Nathan Stone, Extension specialist - section leader at UAPB, and colleagues evaluated the effects of diet composition and feeding frequency on the growth and production of golden shiners. Juvenile golden shiners (initial individual weight = 0.46 g) were stocked into 12, 0.1-acre earthen ponds at a rate of 29,640 fish/acre. Fish were fed either once or twice daily with a control diet or an experimental diet. The diets were similar in protein (42-44 percent) and lipid (9-10 percent), but contained different ingredients. The main difference was the lack of fish meal in the experimental diet, which was designed to match the performance of fish fed

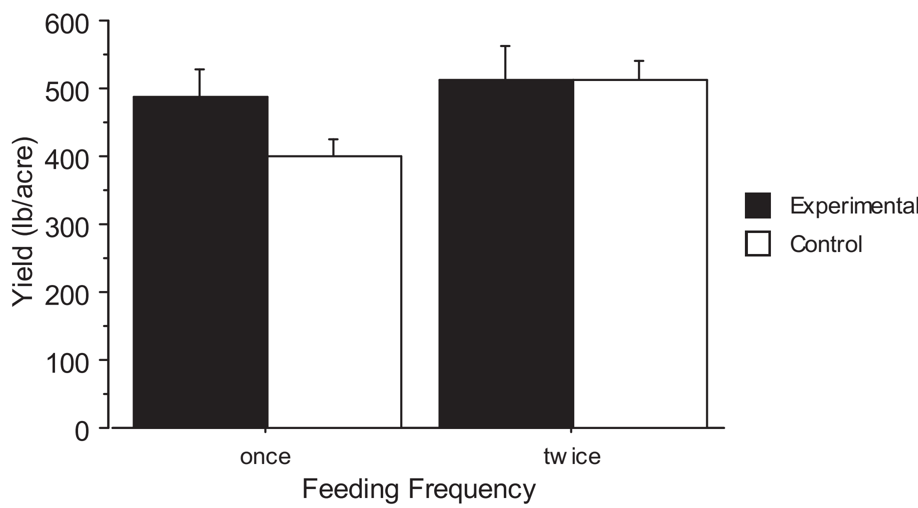


Figure 3. Yield of golden shiners stocked at 30,000/acre for 80 days and fed either once or twice daily at 3% body weight with a 42% crude protein diet with fish meal (Control) or without fish meal (Experimental).

the control diet but at a lower cost. The feed form was an extruded pellet (slow sink). Fish were fed at 3 percent body weight per feeding, adjusted weekly based on an assumed FCR of 1:1 and by sampling every two weeks. Ponds were harvested November 19-20 after 80 days. Average fish weight and survival were estimated by weighing and counting five sub-samples of at least 25 fish. Weights (g) and lengths (mm) of a sample of at least 50 fish per pond were measured to determine condition and size variation. Remaining fish were bulk-weighed.

At harvest, there was no difference in yield (**Figure 3**), average weight or survival due to diet or feeding frequency. Yield averaged 472 lb/acre, survival ranged from 57 to 80 percent and mean weight per fish was 10.2 g. Results showed that feeding a diet with fish meal did not improve yields over a comparable diet formulated with poultry by-products, and that feeding twice a day instead of once a day provided no benefits.

Feed Additives: 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. Lycopene – the carotenoid that makes tomatoes red – is not found naturally in fish, but could be a more sustainable dietary additive to enhance fish coloration if it is effective.

Experiments 1, 2 and 3

In Experiment 1, duplicate groups of 100 uniform juvenile goldfish with initial individual 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 Experiment 2, goldfish from Experiment 1 were used to conduct an indoor washout study that consisted of two sub-experiments (2a and 2b). In Sub-experiment 2a, goldfish were fed the same diet as in Experiment 1, while in Sub-experiment 2b, the goldfish were fed only the basal diet (2.8 mg astaxanthin/kg diet). In Experiment 3, 50 juvenile goldfish with an initial individual weight of 0.77 g were reared in 25 110-L aquaria and fed the same diets as in Experiment 1 for 49 days. In Experiment 1, there were no differences in average individual weight gain, survival or color measures [lightness (L*), redness (a*), yellowness (b*), chroma (C*) or hue (H*)] of fish fed different diets. In Sub-experiments 2a and 2b, there were no differences in change in lightness (ΔL*), redness (Δa*), yellowness (Δb*), chroma (ΔC*) or hue (ΔH*) after the washout study period. In Experiment 3, there were no differences in average individual weight gain and survival among treatments. However, goldfish fed diets containing 100 mg astaxanthin/kg had higher a* (red) than all other treatments (**Table 23**) while there were no differences in other color parameters. Data indicated that dietary astaxanthin supplementation is necessary for enhanced coloration of goldfish in the absence of natural foods. Lycopene was not effective in enhancing red/orange coloration in goldfish.

Table 23. 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^{x}	0.92^{x}	25.73^{x}	25.77^{x}	88.05^{x}
66.0 Astax	76.31^{x}	1.59^{yz}	24.10^{x}	24.19^{x}	86.19^{x}
100.0 Astax	75.70^{x}	1.78^{y}	25.21^{x}	25.31^{x}	85.96^{x}
50.0 Lyco	77.47^{x}	1.30^{xy}	23.77^{x}	23.83^{x}	86.89^{x}
100.0 Lyco	75.68^{x}	1.21^{xz}	23.70^{x}	23.76^{x}	87.09^{x}

[1]Data are means 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 Fisher's least significant difference test ($P \leq 0.05$).

Feed Additives: Prebiotics

Prebiotics are nonliving indigestible carbohydrates that can be added to the diet to improve feed conversion, stimulate the immune response and sometimes improve other functions. Researchers conducted three experiments to determine whether diets with a prebiotic composed of dairy and yeast products could improve performance of golden shiners. The experiments were done in indoor systems with no natural foods, and in outdoor pools and ponds. In all experiments the diets were similar to a commercial formulation (30-35 percent protein), except that low- (4 percent) and high- (10 percent) fat versions of the diets were compared in tanks and pools. Half of the diets (one low-fat and one high-fat diet) contained no prebiotic, and the other two diets had 2 percent prebiotic, as recommended by the manufacturer.

Experiment 1 (Aquaria)

Golden shiners (initial individual weight = 1.15 g) were stocked at 25 fish per 29-gallon aquarium in four aquaria per diet. Fish were fed twice daily to apparent satiation and group-weighed every two weeks for 14 weeks. After harvest, fish were fed the diets for two more weeks before they were exposed to bacteria that cause *Columnaris* disease. After the challenge, mortalities were recorded twice daily for 10 days. Results are shown in **Table 24**. There were no differences in weight gain, survival or body composition, but there was a slight decrease in FCR of fish fed the high-fat diet with prebiotic. After the feeding trial, researchers performed a bacterial challenge on golden shiners fed the standard diet (4 percent poultry fat), a 10 percent poultry fat diet or a diet with both 10 percent poultry fat and 2 percent Grobiotic®-A. Golden shiners fed the diet with Grobiotic®-A had higher survival than fish fed the other diets.

Experiment 2 (Outdoor Pools)

The same diets as in Experiment 1 were fed to golden shiners (initial individual weight = 0.46 g) stocked at 400 fish per pool (1,069-gallon) for 10 weeks. The pools were fertilized to stimulate plankton growth before stocking. Natural food in the pools was determined using Secchi-depth measurements (a measure of water clarity) and chlorophyll a readings (an indication of algae). Fish were fed twice daily to apparent satiation and group-weighed once a month to track growth. After harvest, a subset of fish was moved to indoor tanks and the fish were fed the same diets for two weeks while they got used to the tanks. Then, a bacterial challenge was performed as before, except that fish in half of the tanks were stressed by crowding them in a small basket within the tank before exposure to bacteria. Results are shown in **Table 24**. There were no differences in weight gain or FCR among diets.

Table 24. Effects of a dairy/yeast prebiotic on standard performance and survival of golden shiner following exposure to bacteria that cause *Columnaris*.

Trial type/length	Standard performance criteria (*FCR = feed conversion ratio)	Survival after *Columnaris* (bacteria) exposure
Tank/14-16 wks	No effect on weight gain, survival or body composition; decreased FCR in high-fat (10%) diet with prebiotic	Prebiotic significantly increased survival (no prior stress required)
Pool/10-12 wks	No effect on weight gain or FCR; slight but inconsistent effects on survival and condition index ("plumpness")	Prebiotic in unstressed fish: – No effect on survival Prebiotic in fish stressed by crowding before exposure: – Significant increase in survival
Pond/7-9 wks	No effect on weight gain, net yield or FCR. Condition index higher in fish fed the diet without prebiotic	Prebiotic in unstressed fish: – No effect on survival Prebiotic in fish stressed by crowding before exposure: – Significant increase in survival

The slight differences in survival and condition index were not consistently related to the prebiotic content of the diet.

Experiment 3 (Ponds)

Golden shiners were stocked (initial individual weight = 0.1 g) into ten 0.1-acre ponds (five ponds per diet) at a rate of 87,700 fish/acre and fed a control diet (no prebiotic) or the same formula with 2 percent prebiotic. Both diets were custom-made 35 percent-protein diets extruded as 1.5-mm pellets. Fish were fed to satiation twice daily (4-7 percent body weight) for seven weeks. Subsamples of fish (100 per pond) were counted and weighed every two weeks to track growth. Due to small initial fish size and the relatively low stocking density, growth was very rapid and the study was harvested early to avoid reproduction. After harvest, a subset of fish was moved to indoor tanks and the fish were fed the same diets while they acclimated to the new tanks. Then, a bacterial challenge was performed as for the pool trial. Results are shown in **Table 24**. There were no differences in weight gain, net yield or feed conversion between diets. Condition index was higher in fish fed the control diet without prebiotic. As in the pool trial, fish that had been fed the diet with prebiotic had higher survival after crowding stress and exposure to *Columnaris* bacteria than fish that were not stressed or fed the diet with prebiotic before bacterial exposure.

Overall, the prebiotic had limited effects on general performance of golden shiners. However, the prebiotic significantly improved survival of golden shiners exposed to the bacterium that causes *Columnaris* disease. In systems with natural foods (pools or ponds), it was necessary to impose a stressor (crowding) on the fish before exposure to bacteria to get a statistically significant increase in survival of fish fed prebiotics. However, it is probably not possible to avoid all potential sources of stress in baitfish production (holding, grading, hauling, etc.), and the use of a safe product like prebiotic in the diet should be an effective method of improving survival after harvest. In addition, the prebiotic was effective in golden shiners in ponds even at a low stocking density, where natural foods typically have more impact on fish performance than in indoor systems. Based on a partial budget analysis of the pond data, prophylactic use of the prebiotic should also be economically feasible for golden shiners.

Experiments 4 (Aquaria) and 5 (Outdoor Pools)

Similar trials with goldfish fed the same diets as in Experiments 1 and 2 have been completed. In aquaria, there were no differences in growth or survival of fish fed diets with or without a prebiotic. However, in outdoor pools the prebiotic enhanced growth and condition index of goldfish compared to fish fed the diet with no prebiotic. Goldfish from the aquarium and pool trials were also challenged with the bacteria that cause *Columnaris* disease using the protocol described in Experiment 2. Although clear signs of infection were present in many of the fish after several days, very little mortality occurred and diet differences were not observed.

Although goldfish were more responsive to the prebiotic in terms of weight gain and condition index, no stimulation of the specific immune response occurred, as indicated by survival after the bacterial challenge. Enhanced immune response is probably more beneficial for baitfish than rapid growth, so the dairy/yeast prebiotic tested may have less practical application for goldfish. However, many other prebiotics and probiotics on the market have not been tested in baitfish, and a variety of immune responses should be tested for thorough evaluation of their effectiveness in different baitfish species.

SUMMARY

Considerable information has accumulated on the nutrient requirements and practical diet development 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. There appear to be few differences in nutrient requirements among these species, although there is more information 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 are 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.

SOURCES OF INFORMATION

Chen, R., R. Lochmann, A. Goodwin, K. Praveen, K. Dabrowski and K.J. Lee. (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., R. Lochmann, A. Goodwin, K. Praveen, K. Dabrowski and K.J. Lee. (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 D.M. Gatlin 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.

Li, P., B. Ray, D.M. Gatlin III, T. Sink, R. Chen, and R. Lochmann. (2008) Effect of handling and transport on cortisol response and nutrient mobilization of golden shiner, *Notemigonus crysoleucas*. *Journal of the World Aquaculture Society*, in press.

Liao, H., C.L. Pierce, D.H. Wahl, J.B. Rasmussen and W.C. Leggett. 1995 Relative weight (Wr) as a field assessment tool: relationships with growth, prey biomass and environmental conditions. Transactions of the American Fisheries Society 124:387-400.

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

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

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

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

Lochmann, R., K. Dabrowski, R. Moreau and H. Phillips. (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.T., K.B. Davis and B.A. Simco. (2002) Cortisol response of juvenile golden shiner, *Notemigonus crysoleucas*, diets differing in lipid content. *Fish Physiology and Biochemistry* 27,29-34.

Lochmann, R., H. Phillips, S. Dasgupta, D. Gatlin and S. Rawles. (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.T., T.D. Sink and H. Phillips. (2008) Effects of dietary lipid concentration, a dairy/yeast prebiotic, and fish and nonfish protein sources on growth, survival and nonspecific immune response of golden shiners in indoor tanks and outdoor pools. *North American Journal of Aquaculture*, in press.

Lochmann, R., N. Stone, H. Phillips and M. Bodary. (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.

Lochmann, S.E., K.J. Goodwin, R.T. Lochmann, N.M. Stone and T. Clemment. (2006) Volume and lipid, fatty acid, and amino acid composition of golden shiner eggs during a spawning season. *North American Journal of Aquaculture* 69,116-126.

Mann, R.H.K. (1991) Growth and reproduction, pp. 219-240 In: Winfield, I.J., and Nelson, J.S. (eds) *Cyprinid Fishes: Systematics, Biology, and Exploitation*. Chapman and Hall, London.

Nose, T. 1979. Page 145 In: Yoshida, A., Naito, H., Niiyama, Y., and Suzuki, T., (eds) *Finfish Nutrition and Fishfeed Technology, Volume 1*. Heenemann, Berlin.

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

Robinson, E.H., R.P. Wilson and W.E. Poe. (1980) Re-evaluation of the lysine requirement and lysine utilization by fingerling channel catfish. *Journal of Nutrition* 110, 2313-2316.

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

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

Sink, T.D., and R.T. Lochmann. (2008) Preliminary observations of mortality reduction in stressed, *Flavobacterium columnare*, challenged golden shiners after treatment with a dairy-yeast prebiotic. *North American Journal of Aquaculture* 70,192–194.

Sink, T.D., S. Kumaran and R.T. Lochmann. (2007) Development of a whole-body cortisol extraction procedure for determination of stress in golden shiners, *Notemigonus crysoleucas*. *Fish Physiology and Biochemistry* 33,189-193.

Sink, T.D., R.T. Lochmann, A.E. Goodwin and E. Marecaux. (2007) Mortality rates in golden shiners fed high-fat diets with or without a dairy-yeast prebiotic before challenge with *Flavobacterium columnare*. *North American Journal of Aquaculture* 69,305-308.

SRAC (Southern Regional Aquaculture Center). 2007 Feed formulation and feeding strategies for bait and ornamental fish, pp. 7-10 In: Twentieth Annual Progress Report. United States Department of Agriculture, Cooperative State Research, Education and Extension Service.

Stone, N., E. Park, L. Dorman and H. Thomforde. (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.

APPENDIX 1. WEIGHT CONVERSION CHART FOR MINNOWS

Lb/ 1000	Count #/lb	Grams (g)
0.5	2,000	0.23
1	1,000	0.45
2	500	0.91
3	333	1.36
4	250	1.8
5	200	2.3
20	50	9.1
25	40	11.3

Common Conversion Factors (Metric to English)

1 mg/L = 1 part per million (ppm)

1 mg/kg = 1 part per million (ppm)

1 g/L = 1 part per thousand (ppt)

1 kg = 2.205 lbs

1 hectare (ha) = 2.5 acres

1 kg/ha = 0.882 lbs/acre

2.54 cm = 1 inch

25.4 mm = 1 inch

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