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Catfish Vitamin Nutrition

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Introduction

Vitamins -- a group of organic compounds that are highly diverse in chemical structure and physiological function -- are required in the diet for normal growth, health, and reproduction of fish and other animals. Some animals are able to synthesize certain vitamins in the body in quantities sufficient to meet metabolic needs; thus, those vitamins do not have to be provided in the diet. The vitamin nutrition of channel catfish has been the subject of numerous research reports, which has culminated in the development of a vitamin premix that is used to provide supplemental vitamins in commercial catfish feeds. The premix contains all essential vitamins in sufficient quantities to ensure optimum fish growth and health and to compensate for losses during feed manufacture and storage.

The composition of catfish vitamin premixes has been based on vitamin requirements determined with small, rapidly growing catfish raised under laboratory conditions. These values have been considered sufficient to meet the needs of pond-raised fish. However, vitamin requirements may be affected by several factors, including fish size, environmental conditions, and fish health. Vitamins inherent in feedstuffs used in commercial catfish feeds are usually not considered when formulating catfish feeds because their bioavailability is not known, but they may be a significant source of vitamins. Pond organisms such as zooplankton contain relatively high concentrations of vitamins, but their contribution to the vitamin nutrition of catfish is also unknown. Since several factors may influence the vitamin nutrition of pond-raised catfish, vitamin requirements determined under conditions that reflect those used in the commercial culture of catfish would allow fish nutritionists to formulate catfish feeds that more precisely meet the vitamin needs of the fish.

The information presented in this bulletin includes a brief summary of the vitamin nutrition of catfish. However, the emphasis of the bulletin is on practical vitamin nutrition of catfish based on data from vitamin studies conducted at Mississippi Agricultural and Forestry Experiment Station research facilities over the last several years. Recommendations are made concerning vitamin supplementation of commercial catfish feeds.

This bulletin is intended to provide a brief overview of the vitamin nutrition of catfish. It also presents technical data from studies conducted at the Delta Branch Experiment Station in Stoneville that provide new information on practical vitamin requirements of catfish. Recommendations are given on vitamin supplementation of commercial catfish feeds. English units are used to present technical data because the bulletin is intended to be useful to practicing nutritionists and catfish producers, as well as other scientists.

Vitamin Requirements and Deficiency Signs

Table 1 summarizes qualitative and quantitative vitamin requirements for channel catfish and characteristic vitamin deficiency signs, which can be induced in catfish fed purified diets deficient in a particular vitamin and raised under controlled conditions in the laboratory. Vitamin deficiencies rarely occur in wild fish populations because fish growth in the wild is relatively slow and natural foods contain adequate amounts of all vitamins to meet the needs of the fish. Vitamin deficiencies are more likely to occur in cultured fish because manufactured feeds promote fast fish growth. Therefore, the cultured fish's vitamin requirements are higher. Nevertheless, frank signs of vitamin deficiency are uncommon in cultured fish because commercial feeds contain a vitamin supplement that is generally more than adequate to meet the fish's needs. Occasionally, however, abnormalities similar to vitamin C or pantothenic acid deficiency signs have been observed in cultured fish. These instances are so rare and so isolated that it is difficult to attribute them to a generalized deficiency in the diet.

Vitamins and Disease Resistance

Vitamins and other nutrients are essential for the proper function of the immune system. There is certainly a lot of attention given to the role of vitamins in the health of humans and other animals, and there have been conflicting reports on the amount of various vitamins that must be ingested to elicit the proposed response. Likewise, there has been considerable interest among catfish researchers and catfish producers concerning the use of megadose levels of certain vitamins to enhance disease resistance in catfish, and there have been conflicting reports as to the value of this practice. Early evidence indicated that high levels of vitamin C reduced mortality from certain bacterial diseases of catfish. As a result, some catfish producers fed a high-C feed, which contained about 2,000 parts per million (ppm) of vitamin C, during late winter or early spring, hoping to enhance immune function of the fish. Data from at least six MAFES-supported studies over the last few years indicate that high levels of vitamin C in the diet of catfish are not necessary to enhance disease resistance. Concentrations of vitamin C as low as 25 ppm have been shown to be sufficient to enhance survival of catfish during challenge with the bacterium *Edwardsiella ictaluri*. Commercial catfish feeds are generally supplemented with enough vitamin C to provide 80 to 100 ppm of the vitamin in the final feed, which appears to be in excess of that needed for fish health and normal growth. The effects of other vitamins on immune function of catfish have been investigated. Although specific changes have been measured in certain aspects of immunity at the molecular level, there has been no conclusive evidence that increasing the concentrations of supplemental vitamins improves the resistance of cultured catfish to infectious diseases.

Vitamins in Feeds

The concentrations of vitamins found in feedstuffs commonly used in animal feeds can be found in various feed ingredient tables, and this information can be used to estimate vitamin concentrations in formulated feeds. However, the actual concentration and the estimated value may vary considerably since tabular values are averages and the concentration of vitamins in a particular feed ingredient may vary from batch to batch. A comparison of vitamin concentrations, which were calculated from tabular values or determined analytically, is presented in Table 2. The data are based on a catfish feed that had the following ingredient composition: soybean meal (34%), cottonseed meal (10%), corn (25%), wheat middlings (20%), menhaden fish meal (4%), meat and bone/blood meal (4%), fish oil (1.5%), dicalcium phosphate (1%), and trace minerals. The data show that there is significant variation between vitamin concentrations calculated from tabular values and those determined by analysis (Table 2). In addition, the data show that the feed without supplemental vitamins contains enough thiamin, pyridoxine, niacin, and choline to meet dietary requirements. However, the bioavailability of these vitamins to catfish is not known. Even so, indirect data indicate that vitamins inherent in feed ingredients are utilized fairly effectively by catfish. The information presented in Table 2 also shows that a catfish feed supplemented with a standard vitamin premix meets or exceeds the dietary vitamin requirements of catfish. In fact, many of the vitamins exceed the dietary requirement by several times.

Natural Foods

Because of the high level of nutrients introduced by feeding, commercial catfish ponds are fertile and thus normally contain large numbers of organisms, including phytoplankton, zooplankton, and invertebrates such as insects and crustaceans. Many of these organisms are high in protein, vitamins, and other essential nutrients (Table 3). The degree to which natural food organisms contribute to the nutrition of intensively grown catfish is still unclear. It appears that the contribution of natural food organisms to the protein and energy requirements of catfish is somewhat low, but these organisms may provide significant quantities of vitamins and other nutrients that are required in trace amounts. Studies discussed in other sections of this bulletin have shown that vitamin deficiencies can be produced by feeding catfish purified diets devoid of various vitamins in aquaria under controlled laboratory conditions. However, deficiencies could not be produced in catfish raised in ponds and fed practical feeds that lacked a supplement of a specific vitamin. Vitamin requirements were met either from vitamins naturally occurring in feedstuffs, from natural food organisms, from intestinal synthesis, or from a combination of these sources.

Vitamin Requirement Studies

A series of studies to examine practical vitamin requirements of channel catfish has been conducted over the last few years at our research facility. All experiments were conducted in 0.1-acre earthen ponds stocked at a rate of 10,000 fish per acre and managed according to industry practices. All fish were fed once daily to satiation for the duration of the experiment. Fish size and duration of each experiment are given in tables for the specific experiment. Experimental treatments for each study are summarized in Table 4.

Experiment 1

In experiment 1, we evaluated diets containing either a full vitamin supplement, no vitamin supplement, or one-half vitamin supplement (Table 5). There were no differences in fish feed conversion, survival, and hematocrit (percent red blood cells in a given volume of blood), regardless of dietary treatment. There was an increase in feed consumption and weight gain of fish fed the diet containing one-half the supplemental vitamins. However, one would not expect fish fed one-half of a vitamin supplement to gain more weight than fish fed a full supplement of vitamins. Fish weight gain and feed conversion were typical of healthy catfish, regardless of dietary treatment, and there were no gross indications of any dietary vitamin deficiency. There were no marked differences in liver concentrations of B-complex vitamins, regardless of diet, but liver vitamin C and vitamin E concentrations were lower in fish fed no supplemental vitamins (Table 6). This study indicates that vitamins inherent in the diet were utilized, and/or there was some contribution from natural food. In the case of B-complex vitamins, there also may have been some intestinal synthesis. However, it is likely that the largest contribution to the vitamin nutrition of the fish came from dietary ingredients.

Experiment 2

Since the results from experiment 1 were unexpected, we conducted a second experiment to further investigate the need for supplemental vitamins in catfish. In experiment 2, we compared diets that contained either a full vitamin supplement, no vitamin supplement, one-half vitamin supplement, one-fourth vitamin supplement, or a supplement with one-half the normal allotment of B-complex vitamins (Table 7). There were no differences in weight gain, feed consumption, feed conversion, survival, or hematocrit of fish, regardless of dietary treatment. As in experiment 1, there were no differences in the concentration of B-complex vitamins in the liver, but vitamin C concentrations decreased as the vitamin supplement was reduced (Table 8).

The results were again surprising, particularly in regard to vitamin C. There is essentially no vitamin C inherent in feed ingredients used in catfish feeds, and thus a deficiency was expected in fish fed a diet without any supplemental vitamin C. However, no gross efficiency signs were noted, and the fish appeared to be robust and healthy. It has been suggested that low concentrations of vitamin C in liver tissue is indicative of a vitamin C deficiency, but we do not feel that is the case since no overt signs of deficiency were observed. We have conducted other studies in which tissue vitamin C was very low, but deficiency signs were not apparent. Tissue storage of vitamin C reflects excess intake; thus, it is possible to meet dietary requirements for the vitamin without large amounts being deposited in various tissues. The implication from this study is that the fish met their vitamin C requirement from natural food organisms found in the pond, since this is the only available source of the vitamin. If this were the case, it would appear that enough vitamin C was ingested to cover metabolic needs. However, based on liver concentrations, there was little or no excess. Evidence from other studies we have conducted indicates that vitamin C requirement for catfish may be only 15 to 25 ppm, which is less than previously reported. Regardless of the contribution of natural foods to the vitamin C nutrition of catfish, vitamin C supplements are still needed. Variability in the abundance and type of natural food organisms from one pond to another would prevent producers from depending on natural food as the sole source of vitamin C.

Experiment 3

It appeared that supplements of the B-complex vitamins can be eliminated or at least reduced in catfish feeds. However, before such a recommendation could be made, additional studies were conducted to investigate the removal of single B-complex vitamins in diets of pond-raised catfish. Experiment 3 was conducted to evaluate diets containing either a full vitamin supplement, no supplemental riboflavin, one-half the recommended level of supplemental riboflavin, no supplemental niacin, or one-half the recommended level of niacin (Table 9). There were no differences in weight gain, feed consumption, and feed conversion in fish, regardless of dietary treatment. Liver riboflavin concentrations were the same in samples taken in October and February; fish were on full feed in October, but they received little prepared feed in February. Liver niacin concentrations were lower in fish fed no supplemental niacin, but the concentration of niacin in the liver of these fish was still relatively high. There was a decrease in niacin concentrations from October to February. These data support our contention that supplemental riboflavin and niacin may not be necessary in diets of pond-raised catfish.

Experiment 4

Experiment 4 was conducted to evaluate diets containing either a full vitamin supplement, no supplemental thiamin, one-fourth the recommended amount of supplemental thiamin, no pyridoxine, or one-fourth the recommended amount of pyridoxine (Table 10). Weight gain, feed consumption, and feed conversion were not different among fish on the various dietary treatments. There were no differences in the concentration of thiamin in the livers of fish sampled in October, regardless of diet. However, the February liver samples showed a reduced level of thiamin, as compared to the samples taken in October. In addition, February liver samples of fish fed less than a full thiamin supplement had reduced levels of thiamin. Liver concentrations of pyridoxine were not different among fish fed the various diets, but concentrations increased dramatically in February samples, as compared to the October samples. We are unable to explain the increase in liver pyridoxine, since we would have expected it to decrease. The data from this study indicate that supplemental thiamin and pyridoxine may not be needed in feeds for pond-raised catfish.

Experiment 5

Experiment 5 was conducted to evaluate diets containing either a full vitamin supplement, no supplemental pantothenic acid, one-eighth the recommended level of supplemental pantothenic acid, or one-fourth the recommended level of supplemental pantothenic acid (Table 11). There were no differences in weight gain, feed consumption, feed conversion, and survival of fish fed the various diets. Liver concentrations of the vitamin were similar for fish on each treatment, and there were no differences in liver concentrations measured in October or in February. These data indicate that supplemental pantothenic acid may not be needed in feeds for pond-raised catfish.

Experiment 6

To verify data from the previous experiments, experiment 6 was conducted to evaluate diets containing either a full vitamin supplement, no supplemental pantothenic acid, no supplemental pyridoxine, no supplemental thiamin, no riboflavin, or no niacin (Table 12). An additional diet included a choline supplement. Choline was deleted from some catfish premixes several years ago, and it was not part of the control vitamin premix used for our studies.

There were no differences in weight gain, feed conversion, survival, or blood test results of fish, regardless of dietary treatment. There were no consistent differences in liver concentrations of the various vitamins of samples taken in October or February (Table 13). Liver pantothenic acid and thiamin concentrations were lower in fish fed diets containing no supplemental pantothenic acid or no supplemental thiamin, as compared to fish fed a full vitamin supplement. Liver concentrations of choline were somewhat higher in fish fed a choline supplement, but they were very high in fish fed a diet without the supplement. Liver vitamin concentrations of the other vitamins were not remarkably different among fish fed diets with and without a specific vitamin. These findings support data from the other studies that indicate certain of the B-complex vitamins are not needed in feeds for pond-raised catfish.

Stress Response Experiment

The effects of acute confinement of fish from the above experiments were evaluated by the Department of Biology at the University of Memphis. Fish were confined for 6 hours, and blood samples were taken after 1 and 6 hours of confinement and 12 hours after release. Plasma chloride and osmotic pressure were stable throughout the confinement. Cortisol concentrations were elevated 1 and 6 hours after confinement, but returned to preconfinement concentrations 12 hours after release. The lack of supplemental vitamins in the feed did not impair the ability of the fish to mount or maintain cortisol secretion. These data indicate that sufficient concentrations of vitamins were available to fish fed diets without a vitamin supplement or containing a reduced allotment of vitamins to overcome the effects of acute stress.

Vitamin Stability Studies

Floating catfish feeds are manufactured by extrusion, which involves high pressure, high temperature, and high moisture conditions that are conducive to the destruction of vitamins. Losses of vitamin C, which is particularly sensitive to oxidation during feed manufacture, may be as high as 50% unless a stabilized product is used. To ensure that adequate vitamin C is retained in a floating catfish feed, either a stabilized form is used or excess ascorbic acid is added to compensate for losses during feed manufacture. Generally, it is more economical to over-fortify with an unstablized form of the vitamin. However, if feeds are to be stored for several weeks, a stable form of vitamin C is usually warranted.

Most vitamin stability research has focused on vitamin C. However, some of the B-complex vitamins are added at levels several times their dietary requirement to compensate for anticipated losses during feed manufacture. We conducted a study to evaluate the stability of B-complex vitamins during manufacture of extruded catfish feeds. Riboflavin, pantothenic acid, and niacin had retention values of 100%, 100%, and 96.3%, respectively. Thiamin mononitrate and pyridoxine hydrochloride were relatively stable, having retention values of 65% and 70%, respectively. Results of this study indicate that large excesses of these vitamins are not necessary to ensure that adequate levels remain after feed processing.

Conclusions and Recommendations

Studies conducted at our research facility indicate that supplementation of commercial channel catfish production diets with B-complex vitamins and vitamin C can be substantially reduced without affecting fish performance. Certain vitamins could possibly be eliminated altogether. Studies conducted on vitamin requirements at the Mississippi State University Department of Biochemistry and at the Texas A&M University Department of Wildlife and Fisheries Sciences indicate that the riboflavin, niacin, and vitamin E requirements for channel catfish are lower than previously reported. These data further indicate that the level of these vitamins in commercial catfish feeds can be reduced. Vitamin concentrations proposed herein for catfish feeds are still relatively conservative, even though some recommendations are considerably lower than previously recommended (Table 14). A reduction in the amount of supplemental vitamin E, thiamin, riboflavin, pyridoxine, and pantothenic acid is recommended, along with the deletion of supplemental choline and niacin. The new recommendations allow for losses during feed manufacture and include a margin of safety. To gain more information on the practical vitamin requirements of catfish, we have initiated a 3-year study to investigate the elimination of supplemental vitamins in feeds for catfish raised in large ponds under a multiple batch, topping system.

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Table 1. Vitamin deficiency signs and minimum dietary levels required to prevent signs of deficiency in catfish. [1]

Vitamin	Deficiency signs[2]	Units	Requirement[3]
Fat-soluble			
Vitamin A	Exophthalmia, edema, acities	IU/lb	450-900
Vitamin D	Low bone ash	IU/lb	110-220
Vitamin E	Skin depigmentation, exudative diathesis muscle dystrophy, erythrocyte hemolysis, splenic and pancreatic hemosiderosis	IU/lb	23
Vitamin K	Skin hemorrhage, prolonged clotting time	ppm	R
Water-soluble			
Thiamin	Dark skin color, neurological disorders	ppm	1
Riboflavin	Short-body dwarfism	ppm	9
Pyridoxine	Greenish blue coloration, tetany, nervous disorders	ppm	3
Pantothenic acid	Clubbed gills, anemia, eroded skin, low jaw, fins, and barbels	ppm	15
Niacin	Anemia, lesions of skin and fins, exophthalmia	ppm	14
Biotin	Anemia, skin depigmentation, reduced liver pyruvate carboxylase activity		R
Folic acid[4]	Reduced red blood cells	ppm	1.5
B_{12}	Reduced red blood cells	ppm	R
Choline[5]	Hemorrhagic kidney and intestine, fatty liver	ppm	400
Inositol	None demonstrated		NR
Ascorbic acid	Reduced red blood cells, scoliosis, lordosis, increased susceptibility to bacterial infections, reduced bone collagen formation, internal and external hemorrhage	ppm	60

[1]Adapted from Robinson, E. H. 1989. Channel catfish nutrition. Reviews in Aquatic Sciences 1:365-391.

[2]Anorexia, reduced weight gain, and increased mortality are common vitamin deficiency signs. Thus, these signs are not included in the table.

[3]R and NR refer to "required" and "not required," respectively.

[4]From National Research Council. 1993. Nutrient Requirement of Fish. National Academy Press, Washington,

DC.
[5]Determined using diets marginal in methionine and based on liver lipid concentration.

Table 2. Calculated value[1] and analysis value of selected vitamins in channel catfish feed with or without supplemental vitamins.

Vitamin	Without supplemental vitamins			With supplemental vitamins	
	Calculated	Analysis		Calculated	Analysis
Thiamin (ppm)	6.0	4.9		17.0	12.4
Riboflavin (ppm)	2.3	4.9		15.4	19.8
Pyridoxine (ppm)	5.2	4.8		16.2	23.5
Vitamin B_{12} (ppb)	8.4	20.4		19.4	34.0
Folic acid (ppm)	0.78	1.7		3.0	4.8
Niacin (ppm)	31.1	70.4		119.1	163.8
Pantothenic acid (ppm)	10.1	6.7		45.3	25.7
Vitamin C (ppm)	0	0		162.5	96.5
Choline (ppm)	1,760	2,072		1,760	2,072
Vitamin A (IU/lb)	N/A[2]	<200		4,400	1,090
Vitamin D_3 (IU/lb)	N/A	123		2,200	1,002
Vitamin E (ppm)	20.0	14.7		85.9	80.8
Vitamin K (ppm)	N/A	<11		4.4	<11

[1]Calculated using values from vitamin concentrations given in feed ingredient tables (National Research Council, 1993, Nutrient Requirements of Fish, National Academy Press, Washington DC; Feedstuff Reference Issue, 1997, The Miller Publishing Co., Minnetonka, MN).
[2]N/A = not available.

Table 3. Composition of zooplankton collected during the summer from channel catfish ponds in the Mississippi Delta. [1]

Proximate nutrients (%)	
Dry matter	7.7
Crude protein	72.5
Crude fat	6.2
Crude fiber	10.7
Nitrogen-free extract	8.1
Ash	2.6
Vitamins	
Vitamin D (IU/lb)	111
Vitamin E (ppm)	115
Thiamin (ppm)	3.4

Riboflavin (ppm)	100
Pyridoxine (ppm)	2.5
B_{12} (ppm)	2.2
Folic acid (ppm)	1.2
Niacin (ppm)	141
Pantothenic acid (ppm)	20
Biotin (ppm)	1.5
Inositol (ppm)	1,565
Ascorbic acid (ppm)	164
[1]Dry matter basis.	

Table 4. Dietary treatments for each experiment. [1]

Diet	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5	Experiment 6
1	Control[2]	Control	Control	Control	Control	Control
2	No vitamin mix	No vitamin mix	No riboflavin	No thiamin	No pantothenic acid	No pantothenic acid
3	½ vitamin mix	½ vitamin mix	6.6 ppm riboflavin	2.2 ppm thiamin	4.4 ppm pantothenic acid	No pyridoxine
4		½ B-vitamins	No niacin	No pyridoxine	8.8 ppm pantothenic acid	No thiamin
5		¼ vitamin mix	44 ppm niacin	2.3 ppm pyridoxine		No riboflavin
6						No niacin

[1]Vitamin concentrations refer to supplemental vitamin concentrations.

[2]Control diet was composed of 34.1% soybean meal, 10% cottonseed meal, 25.3% corn screenings, 20% wheat middlings, 4% menhaden fish meal, 4% meat and bone/blood meal, 1% dicalcium phosphate, 1.5% catfish offal oil, 0.025% trace mineral mix, and the following supplemental vitamins: thiamin (11 ppm), riboflavin (13.2 ppm), pyridoxine (11 ppm), pantothenic acid (35 ppm), niacin (88 ppm), folic acid (2.2 ppm), B_{12} (0.01 ppm), ascorbic acid (100 ppm, in final product), A (2,000 IU/lb), D_3 (1,000 IU/lb), E (66 ppm), and K (4.4 ppm). (Robinson, E. H. 1991. A practical guide to nutrition, feeds, and feeding of catfish. MAFES Bulletin 979, Mississippi Agricultural and Forestry Experiment Station.)

Table 5. Mean weight gain, feed consumption, feed conversion ratio (FCR), and survival of pond-raised channel catfish fed the experimental diets in experiment 1.[1]

Diet no.	Supplemental vitamin	Weight gain	Feed comsumption	FCR	Survival	Hematocrit[2]
		lb/fish	lb/fish		%	%
1	Control	0.69 b	0.87 b	1.27	92.7	27.3
2	No vitamin mix	0.63 b	0.84 b	1.33	93.8	26.2

3	½ vitamin mix	0.80 a	1.01 a	1.27	94.3	27.7
SEM[3]		0.03	0.03	0.02	1.7	0.9

[1]Means within a column followed by same letters were not different (P> 0.05, least significant difference test). Average initial weight of fish was 72 pounds per 1,000 fish. The fish were fed once daily to satiation from late April to early October.

[2]Percent red blood cells in a given volume of blood.

[3]SEM = standard error for mean.

Table 6. Mean liver vitamin concentrations of pond-raised channel catfish fed the experimental diets in experiment 1. [1]

Diet no.	Supplemental vitamin	Liver vitamin (ppm)			
		Thiamin	Riboflavin	Pyridoxine	Niacin
1	Control	0.78	7.4 b	3.8	51.1 ab
2	No vitamin mix	0.69	7.6 ab	3.9	49.0 b
3	½ vitamin mix	0.71	7.9 a	3.7	56.8 a
SEM[2]		0.16	0.15	0.18	2.1

[1]Means within a column followed by same letters were not different (P> 0.05, least significant difference test).

[2]SEM = standard error for mean.

Table 6. Continued

Table 6. Mean liver vitamin concentrations of pond-raised channel catfish fed the experimental diets in experiment 1. [1]

Diet no.	Supplemental vitamin	Liver vitamin (ppm)			
		Pantothenic acid	Folic acid	Ascorbate	Alpha-tocopherol
1	Control	12.8	0.79	84.5 a	112.6 a
2	No vitamin mix	16.1	0.58	11.8 c	13.3 c
3	½ vitamin mix	14.9	0.55	59.3 b	72.4 b
SEM[2]		1.7	0.10	5.1	8.4

[1]Means within a column followed by same letters were not different (P> 0.05, least significant difference test).

[2]SEM = standard error for mean.

Table 7. Mean weight gain, feed consumption, feed conversion ratio (FCR), and survival of pond-raised channel catfish fed the experimental diets in experiment 2.[1]

Diet no.	Supplemental vitamin	Weight gain	Feed consumption	FCR	Survival	Hematocrit
		lb/fish	lb/fish		%	%
1	Control	0.98	1.66	1.65	98.8	29.9

2	No vitamin mix	0.98	1.50	1.52	98.5	25.2
3	½ vitamin mix	1.03	1.77	1.71	96.7	31.7
4	½ B-vitamins	0.96	1.87	1.95	95.5	30.2
5	¼ vitamin mix	1.08	1.92	1.78	96.2	30.8
SEM[2]		0.06	0.15	0.14	1.8	3.3

[1]Means within a column were not different (P> 0.05, least significant difference test). Average initial weight of fish was 261 pounds per 1,000 fish. The fish were fed once daily to satiation from late April to early October.
[2]SEM = standard error for mean.

Table 8. Mean liver vitamin concentrations of pond-raised channel catfish fed the experimental diets in experiment 2. [1]

Diet no.	Supplemental vitamin	Liver vitamin (ppm)		
		Riboflavin	Pyridoxine	Niacin
1	Control	5.9	4.6	56.9
2	No vitamin mix	4.4	3.6	54.7
3	½ vitamin mix	6.1	4.5	63.8
4	½ B-vitamins	4.5	4.1	58.5
5	¼ vitamin mix	5.2	4.0	64.2
SEM[2]		0.51	0.39	8.1

[1]Means within a column followed by same letters were not different (P> 0.05, least significant difference test).
[2]SEM = standard error for mean.

Table 8. Continued.

Table 8. Mean liver vitamin concentrations of pond-raised channel catfish fed the experimental diets in experiment 2. [1]

Diet no.	Supplemental vitamin	Liver vitamin (ppm)			
		Pantothenic acid	Folic acid	B_{12}	Ascorbate
1	Control	12.8	0.59	0.13	28.9 b
2	No vitamin mix	10.6	0.70	0.12	5.5 c
3	½ vitamin mix	14.7	0.40	0.14	34.5 b
4	½ B-vitamins	12.2	0.71	0.14	52.8 a
5	¼ vitamin mix	11.4	0.64	0.13	13.1 c
SEM[2]		1.3	0.21	0.011	3.2

[1]Means within a column followed by same letters were not different (P> 0.05, least significant difference test).
[2]SEM = standard error for mean.

Table 9. Mean weight gain, feed consumption, feed conversion ratio (FCR), survival, and liver vitamin concentration of pond-raised channel catfish fed the experimental diets in experiment 3.[1]

Diet no.	Supplemental	Weight	Feed	FCR	Survival

	vitamin	gain	consumption		
		lb/fish	lb/fish		%
1	Control	0.72	1.07	1.56	73.0
2	No riboflavin	0.69	1.02	1.56	68.7
3	6.6 ppm riboflavin	0.74	1.06	1.49	73.7
4	No niacin	0.66	0.97	1.53	73.2
5	44 ppm niacin	0.68	1.02	1.57	73.1
SEM[2]		0.03	0.05	0.04	3.7

[1]Means within a column followed by same letters were not different (P> 0.05, least significant difference test). Average initial weight of fish was 73 pounds per 1,000 fish. The fish were fed once daily to satiation from late May to early October and fed according to winter feeding recommendations from early October to mid-February.
[2]SEM = standard error for mean.

Table 9. Continued.

Table 9. Mean weight gain, feed consumption, feed conversion ratio (FCR), survival, and liver vitamin concentration of pond-raised channel catfish fed the experimental diets in experiment 3.[1]

Diet no.	Supplemental vitamin	Liver riboflavin		Liver niacin	
		Oct.	Feb.	Oct.	Feb.
		ppm	ppm	ppm	ppm
1	Control	2.53	2.70	123.3 a	71.2 b
2	No riboflavin	2.62	3.21		
3	6.6 ppm riboflavin	1.93	3.33		
4	No niacin			109.5 b	75.5 ab
5	44 ppm niacin			129.2 a	83.0 a
SEM[2]		0.42	0.37	3.5	3.2

[1]Means within a column followed by same letters were not different (P> 0.05, least significant difference test). Average initial weight of fish was 73 pounds per 1,000 fish. The fish were fed once daily to satiation from late May to early October and fed according to winter feeding recommendations from early October to mid-February.
[2]SEM = standard error for mean.

Table 10. Mean weight gain, feed consumption, feed conversion ratio (FCR), survival, and liver vitamin concentration of pond-raised channel catfish fed the experimental diets in experiment 4. [1]

Diet no.	Supplemental vitamin	Weight gain	Feed consumption	FCR	Survival
		lb/fish	lb/fish		%
1	Control	0.70	1.12	1.61	86.9 ab
2	No thiamin	0.73	1.17	1.60	91.2 ab
3	2.2 ppm thiamin	0.69	1.13	1.64	83.3 b
4	No pyridoxine	0.73	1.14	1.58	92.1 a

5	2.3 ppm pyridoxine	0.73	1.18	1.64	90.3 ab
SEM[2]		0.03	0.04	0.07	2.5

[1]Means within a column followed by same letter were not different (P> 0.05, least significant difference test). Average initial weight of fish was 60 pounds per 1,000 fish. The fish were fed once daily to satiation from mid-May to early October and fed according to winter feeding recommendations from early October to mid-February.

[2]SEM = standard error for mean.

Table 10. Continued.

Table 10. Mean weight gain, feed consumption, feed conversion ratio (FCR), survival, and liver vitamin concentration of pond-raised channel catfish fed the experimental diets in experiment 4. [1]

Diet no.	Supplemental vitamin	Liver thiamin		Liver pyridoxine	
		Oct.	Feb.	Oct.	Feb.
		ppm	ppm	ppm	ppm
1	Control	5.51	3.40 a	4.3	12.88
2	No thiamin	4.82	1.87 b		
3	2.2 ppm thiamin	3.90	2.11 b		
4	No pyridoxine			4.2	13.25
5	2.3 ppm pyridoxine			3.3	13.05
SEM[2]		2.33	0.28	0.3	0.83

[1]Means within a column followed by same letter were not different (P> 0.05, least significant difference test). Average initial weight of fish was 60 pounds per 1,000 fish. The fish were fed once daily to satiation from mid-May to early October and fed according to winter feeding recommendations from early October to mid-February.

[2]SEM = standard error for mean.

Table 11. Mean weight gain, feed consumption, feed conversion ratio (FCR), survival, and liver vitamin concentration of pond-raised channel catfish fed the experimental diets in experiment 5.[1]

Diet no.	Supplemental vitamin	Weight gain	Feed consumption	FCR
		lb/fish	lb/fish	
1	Control	0.62	1.18	1.90
2	No pantothenic acid	0.62	1.24	2.01
3	4.4 ppm pantothenic acid	0.62	1.24	2.01
4	8.8 ppm pantothenic acid	0.61	1.16	1.88
SEM[2]		0.03	0.06	0.05

[1]Means within a column were not different (P> 0.05, least significant difference test). Average initial weight of fish was 40 pounds per 1,000 fish. The fish were fed once daily to satiation from mid-May to early October and fed according to winter feeding recommendations from early October to mid-February.

[2]SEM = standard error for mean.

Table 11. Continued.

Table 11. Mean weight gain, feed consumption, feed conversion ratio (FCR), survival, and liver vitamin concentration of pond-raised channel catfish fed the experimental diets in experiment 5.[1]				
Diet no.	Supplemental vitamin	Survival	Liver pantothenic acid	
			October	February
		%	ppm	ppm
1	Control	87.4	35.89	26.56
2	No pantothenic acid	89.3	32.29	28.44
3	4.4 ppm pantothenic acid	88.5	28.47	27.66
4	8.8 ppm pantothenic acid	91.5	28.12	31.24
SEM[2]		1.2	6.16	2.94

[1]Means within a column were not different (P> 0.05, least significant difference test). Average initial weight of fish was 40 pounds per 1,000 fish. The fish were fed once daily to satiation from mid-May to early October and fed according to winter feeding recommendations from early October to mid-February.

[2]SEM = standard error for mean.

Table 12. Mean weight gain, feed consumption, feed conversion ratio (FCR), survival, and hematocrit of pond-raised channel catfish fed the experimental diets in experiment 6.[1]			
Diet no.	Supplemental vitamin	Weight gain	Feed consumption
		lb/fish	lb/fish
1	Control	0.66	1.16 b
2	No pantothenic acid	0.69	1.25 ab
3	No pyridoxine	0.68	1.25 ab
4	No thiamin	0.67	1.20 b
5	No riboflavin	0.68	1.22 b
6	No niacin	0.76	1.37 a
SEM[3]		0.04	0.05

Means within a column followed by same letters were not different (P > 0.05, least significant difference test). Average initial weight of fish was 57 pounds per 1,000 fish. The fish were fed once daily to satiation from early May to late October and fed according to winter feeding recommendations from late October to late February.

[2]Percent of red blood cells in a given volume of blood.

[3]SEM = standard error for mean.

Table 12. Continued.

Table 12. Mean weight gain, feed consumption, feed conversion ratio (FCR), survival, and hematocrit of pond-raised channel catfish fed the experimental diets in experiment 6.[1]				
Diet no.	Supplemental vitamin	FCR	Survival	Hematocrit[2]

			%	%
1	Control	1.76	95.7	33.1
2	No pantothenic acid	1.83	88.3	32.9
3	No pyridoxine	1.87	88.0	33.4
4	No thiamin	1.81	91.6	33.8
5	No riboflavin	1.78	92.1	33.6
6	No niacin	1.79	87.2	35.9
SEM[3]		0.08	2.8	1.1

[1]Means within a column followed by same letters were not different (P > 0.05, least significant difference test). Average initial weight of fish was 57 pounds per 1,000 fish. The fish were fed once daily to satiation from early May to late October and fed according to winter feeding recommendations from late October to late February.
[2]Percent of red blood cells in a given volume of blood.
[3]SEM = standard error for mean.

Table 13. Mean liver vitamin concentrations of pond-raised channel catfish fed the experimental diets in experiment 6. [1]

Diet / supplement	Liver vitamin concentration (ppm)					
	Pantothenic acid		Pyridoxine		Thiamin	
	Oct.	Feb.	Oct.	Feb.	Oct.	Feb.
(1)Control	13.1 a	12.3 a	1.78	1.19	1.18	3.50 a
(2) No pantothenic acid	8.4 b	5.5 b				
(3) No pyridoxine			1.63	1.15		
(4) No thiamin					0.73	2.15 b
(5) No riboflavin						
(6) No niacin						
(7) 500 ppm choline						
SEM[2]	0.81	0.73	0.27	0.05	0.22	0.16

[1]Means within a column followed by same letters were not different (P> 0.05, least significant difference test).
[2]SEM = standard error for mean.

Table 13. Continued.

Table 13. Mean liver vitamin concentrations of pond-raised channel catfish fed the experimental diets in experiment 6. [1]

Diet / supplement	Liver vitamin concentration (ppm)					
	Riboflavin		Niacin		Choline	
	Oct.	Feb.	Oct.	Feb.	Oct.	Feb.
(1) Control	11.7 b	10.3	79.6	48.7	1,197	1,443 b
(2) No pantothenic acid						
(3) No pyridoxine						
(4) No thiamin						

(5) No riboflavin	12.8 a	10.0				
(6) No niacin			82.7	45.7		
(7) 500 ppm choline					1,258	1,744 a
SEM[2]	0.26	0.29	2.5	4.0	145	92

[1]Means within a column followed by same letters were not different (P> 0.05, least significant difference test).
[2]SEM = standard error for mean.

Table 14. Previous and current recommended supplementation levels of production diets for pond culture of channel catfish.

Vitamin	Previously recommended supplementation	Currently recommended supplementation
Fat-soluble		
Vitamin A (IU/lb)	2,000	1,000
Vitamin D (IU/lb)	1,000	500
Vitamin E (ppm)	60	30
Vitamin K (ppm)	4.4	4.4
Water-soluble		
Thiamin (ppm)	11	2.5
Riboflavin (ppm)	13.2	6.0
Pyridoxine (ppm)	11	5.0
Pantothenic acid (ppm)	35	15
Niacin (ppm)	88	None
Biotin	None	None
Folic acid (ppm)	2.2	2.2
B12 (ppm)	0.01	0.01
Choline (ppm)	275	None
Inositol	None	None
Vitamin C (ppm)	100	50[1]

[1]Final feed -- amount needed depends on type of vitamin C added.