A Practical Guide to Nutrition, Feeds, and Feeding of Catfish

(Second Revision)

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Preface

Almost 5 years have passed since the publication of the first revision of this report on the status of catfish nutrition and feeding. During that time, several studies have been completed that impact both feed formulation and feeding practices. These new data have been included in the report. Much of the information presented remains unchanged. As in the original report, certain sections are presented in more detail and are more technical than others. We hope the information presented herein is practical and is presented in a usable manner. As stated in the original report, the information presented is intended as a guide because the feeding of catfish, though based on sound scientific evidence, remains in part an "art" as much as a science.

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INTRODUCTION

Nutrition is the process by which an organism takes in and assimilates food. Nutrition involves the ingestion, digestion, absorption, and transport of various nutrients throughout the body where the nutrients in foods are converted into body tissues and activities. Nutrition also includes the removal of excess nutrients and other waste products. Nutrition is a complex but inexact biological science because of the natural variability between individuals of a given species.

Extensive research has been conducted on the nutrition and feeding of catfish, and consequently, their nutrient requirements and feeding characteristics are well documented. These data have served as a basis for the formulation of efficient, economical diets and for the development of feeding strategies — both of which have been instrumental to the success of the catfish industry. Today's catfish producer feeds a nutritionally complete diet that provides all known nutrients at required levels and the energy necessary for their utilization in water-stable, readily digestible form. It is essential to supply all nutrients via the diet because the contribution of microbially synthesized nutrients in the intestine of catfish is minimal. Additionally, the quantity of nutrients supplied from natural food organisms found in pond waters is relatively small in comparison to total nutrient requirements, except perhaps for early life stages such as fry or fingerlings. Although the nutrient requirements of catfish are well known, there are many factors that affect specific nutrient requirements. These include genetics, sex, feed intake, energy density of the diet, nutrient balance and nutrient interaction in the diet, digestibility, presence of toxins or mold in the diet, expected level of performance, desired carcass composition, and environmental factors.

A short summary of catfish nutrition and feeding are presented in the following sections. Topics include digestion, energy, nutrients, nonnutritive dietary components, feeds, feed manufacture, and feeding.

DIGESTION

Digestion is generally thought of as a series of processes that take place in the gastrointestinal tract to prepare ingested food for absorption. These processes involve mechanical reduction of particle size and solubilization of food particles by enzymes, low pH, or emulsification. Once digestion has occurred, absorption (the uptake of nutrients from the gastrointestinal tract into the blood or lymph) may occur by diffusion, active transport, or by pinocytosis (cellular engulfment).

Specific digestive processes have not been extensively studied in catfish, but they are presumed to be similar to that of other simple-stomach animals. The digestive tract of catfish includes the mouth, pharynx, esophagus, stomach, and intestine, as well as the accessory digestive organs pancreas, liver, and gall bladder. The pH of the catfish stomach ranges from 2 to 4, while the intestine ranges from 7 to 9. The digestive enzymes trypsin, chymotrysin, lipase, and amylase have been identified in catfish intestine.

Digestibility coefficients provide an estimate of the usefulness of feedstuffs and of finished feeds; thus, they are useful tools to use when formulating catfish feeds. Digestibility coefficients are more difficult to determine with fish than with terrestrial animals, because nutrients can be lost to the water from the feed or from fecal material collected from the water. Although determining digestibility coefficients is problematic with fish, they have been determined for commonly used feed ingredients for catfish (Tables 1–3).

Protein digestibility coefficients for feedstuffs (Table 1) are generally used in formulating feeds, but a more precise feed formulation can be derived if one uses amino acid availability (Table 2) as the basis for formulating feeds rather than digestible protein. For example, the protein digestibility of cottonseed meal to catfish is about 84%, but the lysine availability is only about 66%. If feeds are formulated on a protein basis using cottonseed meal, a lysine deficiency may result. The major problem in formulating catfish feeds on an available amino acid basis is the lack of sufficient data.

Digestion coefficients for energy, lipid, and carbohydrate (Table 1) have been determined for catfish. Lipids are particularly good energy sources for catfish. Starches are not digested as well as lipid by catfish, but the digestibility of starch by warmwater fish is higher than that of coldwater fish. The level of carbohydrate in the diet appears to affect starch digestion. Starch and dextrin digestion decreases as the dietary level increases. The predominant sources of carbohydrate in catfish feeds are grain products, which are 60–70% digestible.

The availability of minerals from feedstuffs has not been studied to any extent in catfish. Phosphorus availability has been determined for various sources of phosphorus to catfish (Table 3). Generally, phosphorus from plant sources is only about 30–50% available to catfish; phosphorus from animal sources is about 40–80% available.

Table 1. Average apparent digestibility (%) for protein, fat, carbohydrate, and energy of various feedstuffs determined for catfish.

Feedstuffs	International feed number	Protein	Fat	Carbohydrate	Energy
Alfalfa meal (17% [1])	1-00-023	13 [2]			16 [2]
Blood meal (81%)	5-00-380	74 [4]			
Corn grain (10%)	4-02-935	60 [2], 97 [3]	76 [2]	59-66 [2]	26 [2], 57 [3]
Corn grain (cooked) (10%)		66 [2]	96 [2]	62-78 [2]	59 [2], 79 [3]
Corn gluten meal (43%)	5-04-900	92 [4]			
Cottonseed meal (41%)	5-01-621	81 [2], 83 [3]	81 [2]	17 [2]	56 [2], 80 [3]
Fish meal (anchovy) (65%)	5-01-985	90 [2]	97 [2]		
Fish meal (menhaden) (61%)	5-02-009	87 [2], 85 [3], 70-86 [4]			85 [2], 92 [3]
Fish oil			97 [2]		
Meat meal and bone meal (50%)	5-00-388	75 [2], 61 [3], 82 [4]	77 [2]		81 [2], 76 [3]
Peanut meal (49%)	5-03-650	74 [3], 86 [4]	76 [3]		
Poultry by-product meal (61%)	5-04-798	65 [4]			
Poultry feather meal (84%)	5-03-795	74 [2]	83 [2]	67 [2]	
Rice bran (13%)	4-03-928	73 [3]			50 [3]
Rice mill feed (9%)		63 [3]			14 [3]
Soybean meal (44%)	5-04-604	77 [2]	81 [2]		56 [2]
Soybean meal (48%)	5-04-612	84 [2], 97 [3], 85 [4]			72 [2]
Wheat bran (16%)	4-05-190	82 [2]			56 [2]
Wheat grain (13%)	4-05-268	84 [2], 92 [3]	96 [2]	59 [2]	60 [2], 63 [3]
Wheat shorts (17%)	4-05-201	72 [2]			

[1]Values in parentheses represent percentage crude protein.
[2]From Cruz, E.M., 1975, Determination of nutrient digestibility in various classes of natural and purified feed materials for channel catfish, Ph.D. dissertation, Auburn University, Alabama,
[3]From Wilson, R.P. and W.E. Poe, 1985, Apparent digestible protein and energy coefficients of common feed ingredients for channel catfish, Progressive Fish-Culturist 47:154-158.
[4]From Brown, P.B., R.J. Strange, and K.R. Robbins, 1985, Protein digestion coefficients for yearling channel catfish fed high protein feedstuffs, Progressive Fish-Culturist 47:94-97.

Table 2. Average apparent amino acid availabilities (%) for various feedstuffs determined for catfish.[1]

Amino acid	Peanut meal (5-03-650) [2]	Soybean meal (5-04-612)	Meat and bone meal (5-00-388)	Menhaden fish meal (5-02-009)	Corn grain (4-02-935)	Cottonseed meal (5-01-621)	Rice bran (4-03-928)	Wheat middlings (4-05-204)
Alanine	88.9	79.0	70.9	87.3	78.2	70.4	82.0	84.9
Arginine	96.6	95.4	86.1	89.2	74.2	89.6	91.0	91.7
Aspartic acid	88.0	79.3	57.3	74.1	53.9	79.3	82.4	82.8
Glutamic acid	90.3	81.9	72.6	82.6	81.4	84.1	88.8	92.3
Glycine	78.4	71.9	65.6	83.1	53.1	73.5	80.0	85.2
Histamine	83.0	83.6	74.8	79.3	78.4	77.2	70.4	87.4
Isoleucine	89.7	77.6	77.0	84.8	57.3	68.9	81.4	81.8
Leucine	91.9	81.0	79.4	86.2	81.8	73.5	84.1	84.6
Lysine	85.9	90.9	81.6	82.5	69.1	66.2	81.3	85.9
Methionine	84.8	80.4	76.4	80.8	61.7	72.5	81.9	76.7
Phenylalanine	93.2	81.3	82.2	84.1	73.1	81.4	82.9	87.2
Proline	88.0	77.1	76.1	80.0	78.4	73.4	79.5	88.3
Serine	87.3	85.0	63.7	80.7	63.9	77.4	82.0	83.0
Threonine	86.6	77.5	69.9	83.3	53.9	71.8	77.3	78.8
Tyrosine	91.4	78.7	77.6	84.8	68.7	69.2	86.7	83.0
Valine	89.6	75.5	77.5	84.0	64.9	73.2	83.2	84.5
Average	**88.4**	**81.0**	**74.3**	**82.9**	**68.3**	**75.1**	**82.2**	**84.9**

[1]From Wilson, R.P., and E.H. Robinson, 1982, Protein and amino acid nutrition for channel catfish. Mississippi Agricultural and Forestry Experiment Station Information Bulletin No. 25, Mississippi State University, Mississippi.
[2]International feed number.

Table 3. Average apparent phosphorus availability of feedstuffs determined for catfish.

Feedstuffs	International feed number	Availability (%)
Calcium phosphate		
mono basic	6-01-082	94 [1]
dibasic	6-01-080	65 [1], 82 [2]
defluorinated	6-01-780	82 [2]
Sodium phosphate, mono basic	6-04-288	90 [1]
Casein	5-01-162	90 [3]
Egg albumin		71 [3]
Meat & bone/blood meal		84 [2]
Fish meal (anchovy)	5-01-985	40 [1]
Fish meal (menhaden)	5-02-009	39 [1], 75 [2]
Corn grain	4-02-935	25 [1]
Cottonseed meal (41%)	5-01-621	43 [2]
Soybean meal (44%)	5-04-604	50 [1]
Soybean meal (48%)	5-04-612	54 [1], 49 [2], 29 [3]
Wheat middlings	4-05-205	28 [1], 38 [2]

[1]From Lovell, R.T, 1978, Dietary phosphorus requirement of channel catfish, Transactions of the American Fisheries Society 107:617-621. Based on digestibility trial using chromium oxide as an indicator.
[2]From Li, M.H., and E.H. Robinson, 1996, Phosphorus availability (digestibility) of common feedstuffs to channel catfish as measured by weight gain and bone mineralization, Journal of the World Aquaculture Society 27:297-302. Based on weight gain of fish compared with a reference diet containing 0.4% available phosphorus from monobasic sodium phosphate. Weight gain appeared to be a more reliable indicator than did bone phosphorus concentrations.
[3]From Wilson, R.P., E.H. Robinson, D.M. Gatlin III, and W.E. Poe, 1982, Dietary phosphorus requirement of channel catfish, Journal of Nutrition 112:1197-1202. Based on digestibility trial using chromium oxide as an indicator.

Energy

Quantitatively, energy is the most important component of the diet because feed intake in animals that are fed *ad libitum* is largely regulated by dietary energy concentration. Thus, feeding standards for many animals are based on energy needs. Since catfish are not typically fed *ad libitum*, feed intake may be more of a function of feed allowance than of the dietary energy concentration, except when the fish are fed to satiety. Although catfish feed intake may not be strictly regulated by the dietary energy concentration, balance of dietary energy in relation to dietary nutrient content is important when formulating catfish feeds. This is true primarily because a deficiency of nonprotein energy in the diet will result in the more expensive protein being used for energy. In addition, if dietary energy is excessively high, food intake may decline, resulting in a reduced intake of essential nutrients. An excessive high dietary energy/nutrient ratio may lead to an undesirable level of visceral or tissue fat that may reduce dressed yield and shorten shelf life of frozen products.

One of the most notable differences in the nutrition of fish as compared with other livestock concerns energy requirements. For example, less energy is required for protein synthesis in fish. The protein gain per megacalorie (Mcal) of metabolizable energy (ME) consumed is 47, 23, 9, and 6 grams for catfish (ME estimated), broiler chickens, swine, and beef cattle, respectively. Maintenance energy requirements are lower for fish than for warm-blooded animals because fish do not have to maintain a constant body temperature and they expend less energy to maintain their spacial position. Losses of energy in urine and gill excretions are lower in fish because most nitrogenous waste is excreted as ammonia instead of urea or uric acid. In addition, the increase in energy cost associated with the assimilation of ingested food (i.e., heat increment) is less in fish.

Dietary energy should be expressed in a manner that reflects available (usable) energy. Gross energy, which is a measure of the heat liberated on complete oxidation of a compound, is not a practical indicator of usable energy because certain compounds are not as digestible as others are. As an example, gross energy for starch and cellulose is similar, but the digestible energy (DE) — defined as gross energy minus fecal energy losses — from starch for catfish is about 2.5–3.0 kcal/gram and essentially zero for cellulose. Since gross energy is of little practical value in expressing usable energy values for catfish, digestible energy is often used to express the dietary energy of catfish feeds.

Metabolizable energy — DE minus energy losses from the urine in livestock or urine and gills in fish — is often used to express energy content of feeds. For farmed animals, theoretically, using ME to express dietary energy may be more desirable than using DE, since ME is a more precise measure of available energy for metabolism. In addition, ME has been adopted by the National Research Council for use in formulating animal feeds. However, in a practical sense, there is little advantage in using ME values rather than DE values in formulating fish feeds because losses in digestion account for most of the variation in losses of gross energy. Also, energy losses through the gills and urine by fish are smaller than nonfecal losses in other animals and do not vary among feedstuffs as much as fecal losses.

Energy requirements of catfish were largely neglected in the early stages of catfish feed development primarily because an imbalance in dietary energy does not appreciably affect the health of the fish. Also, feeds prepared from feedstuffs typically used in catfish feeds, such as soybean meal, corn, and fish meal, are unlikely to be extreme in respect to energy balance. As it turns out, these assumptions were more or less true. However, correct balance of dietary energy is an important consideration when formulating catfish feeds because too much energy can result in a reduction in food intake and thus reduce nutrient intake. In addition, excess dietary energy may result in an increased deposition of body fat. If the dietary energy level is too low, protein will be used for energy instead of tissue synthesis.

Absolute energy requirements for catfish are not known. Estimates of the requirement have been determined by measuring weight gain or protein gain of catfish fed diets containing a known amount of energy. Energy requirements reported for catfish, which have generally been expressed as a ratio of DE to crude protein (DE/P), range from 7.4–12 kcal/gram. These values are considerably lower than the DE/P ratios of 16–25 kcal/gram reported for swine and poultry. Based on current knowledge, a DE/P ratio of 8.5–10 kcal/gram is adequate for use in commercial catfish feeds. Increasing the DE/P ratios of catfish diets above this range may increase fat deposition, and if the energy value is too low, the fish will grow slowly.

Catfish can use amino acids, lipids, and carbohydrates for energy. Lipids and amino acids are more readily used than are carbohydrates. However, catfish and certain other warmwater fish use carbohydrates more efficiently than do coldwater fish such as the rainbow trout. Catfish digest about 65% of uncooked cornstarch when fed a diet containing 30% of corn. Cooking increases digestibility of cornstarch to about 78%. Corn that has been processed by extrusion is 38% more digestible by catfish than corn processed using a pellet mill. Although lipids and amino acids are more highly digestible by catfish than are carbohydrates, the major source of energy in commercial catfish diets is from carbohydrates contained in grains and grain milling by-products. Carbohydrates, which are the least expensive source of energy, are used to spare protein for growth. Lipids, which are the most concentrated and most highly digestible sources of energy that can be used in catfish feeds, are used sparingly because of several negative aspects of using high levels in catfish diets (see “Lipid” under “Nutrients”).

NUTRIENTS

Qualitatively, 40 nutrients have been identified as necessary for the normal metabolic function of catfish. The quantitative requirements for most nutrients have been identified for catfish (Tables 4–6). Nutritional requirements for catfish have generally been based on weight gain and feed efficiency of small fish raised under laboratory conditions presumed to be near optimum. However, over the past several years, data have been collected on the nutrient requirements of catfish raised under practical conditions. Those data are included within this report.

Carbohydrates

Carbohydrates are a group of compounds — composed of carbon, hydrogen, and oxygen — that include sugars, starches, cellulose, gums, and other closely related substances. They are among the most abundant organic compounds found in nature. Carbohydrates are the primary forms of energy stored in seeds, roots, and tubers. Plants use solar energy to synthesize carbohydrates from carbon dioxide and water through photosynthesis, a process essential to all animal life since it provides energy and oxygen for life processes. Animal tissues contain small amounts of carbohydrates, which are stored mainly as glucose in the blood and glycogen in the liver and muscle tissues. Animal blood contains about 0.05% to 0.1% circulating glucose, which is used for energy and is replenished from stores of glycogen in the liver.

Carbohydrates have several functions in animals. They serve as an energy source, tissue constituents (e.g., blood glucose, liver glycogen, and nucleotides), and precursors of certain metabolic intermediates. However, since animals are capable of synthesizing carbohydrates from lipid and protein, they do not require carbohydrates in the diet for normal growth and functions.

Ability to use dietary carbohydrates as an energy source differs among fish species. Most fresh- and warmwater fish, including catfish, can use much higher levels of dietary carbohydrates than coldwater or marine fish. This may be attributed to the fact that warmwater fish have a much higher intestinal amylase activity than coldwater species. Enzymes for the digestion and metabolism of carbohydrates have been detected in several fish species. However, hormonal and metabolic control of carbohydrate metabolism in fish remains unclear and may differ from that of mammals.

The polysaccharides dextrin and starch are well used by catfish. However, utilization of mono- and disaccharides by catfish is not as efficient. Studies indicate that catfish metabolize glucose in a manner similar to mammals but at a much slower rate. Catfish apparently lack enzyme or endocrine systems capable for rapid metabolism of glucose.

Although animals do not have a dietary carbohydrate requirement, catfish feeds should contain adequate amounts of grain or grain by-products that are rich in starch. Starch not only provides the least expensive energy source but also aids in feed manufacture.

Starch helps to bind feed ingredients together and to increase expansion of extruded feeds so that the feed pellets are water-stable and can float in the water. A typical catfish feed contains 25% or more soluble (digestible) carbohydrates, plus an additional 3–6% of carbohydrates that are generally present as crude fiber (mainly cellulose). Crude fiber is considered indigestible by catfish. Fiber is undesirable in the fish feeds because indigestible materials may "pollute" the water. However, there is always some fiber inherent in practical feed ingredients.

Lipid

Lipids (fats and oils) are a highly digestible source of concentrated energy; it contains about 2.25 times as much energy as does an equivalent amount of carbohydrates. Lipids play several important roles in an animal's metabolism, such as supplying essential fatty acids, serving as a vehicle for absorption of fat-soluble vitamins, and serving as precursors for steroid hormones and other compounds. The use of lipids in fish feeds may increase feed palatability. Body lipid stores affect the flavor of fish as well as help maintain neutral buoyancy. The type and amount of lipid used in catfish diets is based on essential fatty acid requirements, economics, constraints of feed manufacture, and quality of fish flesh desired.

Essential fatty acids (EFA) are ones that cannot be synthesized in the animal's body; thus, they must be provided in the diet. EFAs are classified based on their chemical structure and are designated as either omega-3 (n-3) or omega-6 (n-6) fatty acids. In general, fish appear to require n-3 fatty acids, while land animals appear to require n-6 fatty acids. However, this generalization does not always hold true.

Certain fish (including some species of tilapia and carp) apparently require both n-3 and n-6 fatty acids. The EFA requirements for catfish and most other warmwater fish have not been precisely defined, but catfish apparently require a small amount of n-3 fatty acids. It appears that 1–2% dietary linolenic acid (18:3 n-3) is as good as 0.5–0.75% highly unsaturated fatty acids for normal growth, because catfish apparently elongate and desaturate linolenic acid to synthesize highly unsaturated fatty acids. The EFA requirement can be supplied by marine fish oil such as menhaden oil. Natural food organisms, such as zooplankton, found in the pond are also a good source of EFA.

Catfish appear to have the ability to synthesize most of their fatty acids; thus, nutritionally there may be no "best" level of dietary lipid except that needed to provide EFA. Generally, weight gain and feed efficiency are depressed when fish are fed diets containing 15% or more lipid. Catfish have been fed diets containing up to 16% lipid without conclusive evidence as to which level is best for optimum growth. Even so, there is likely an optimum level of lipid to be used in catfish feeds with respect to protein sparing, product quality, and constraints of feed manufacture.

Since lipid is a concentrated source of energy and can spare the more expensive protein, some lipid should be included in catfish diets. However, too much dietary lipid may result in excessive fat deposition in the body cavity and tissues that may adversely affect processing yield, product quality, and storage of processed products. Also, high-lipid feeds are more difficult to pellet, but if needed, supplemental lipid can be sprayed onto the finished feed pellets. Lipid levels in commercial feeds for food-sized catfish rarely exceed 5–6%. About 3–4% of the lipid is inherent in the feed ingredients, with the remaining 1–2% being sprayed onto the finished pellets. Spraying feed pellets with lipid increases dietary energy and aids in the reduction of feed dust ("fines").

A mixture of vegetable and animal lipids has been used in commercial catfish feeds. These were recommended over marine fish oils because high levels of fish oil may impart "fishy" flavor to the catfish flesh. In addition, there is evidence that dietary menhaden oil levels of 2% or more reduced survival of catfish exposed to the bacterial pathogen *Edwardsiella ictaluri*. The negative effects of menhaden oil on bacterial resistance are likely caused by the immuno-suppressive effect of highly unsaturated n-3 fatty acids. Catfish feeds manufactured in Mississippi are generally sprayed with catfish oil, which is a local product extracted from catfish offal. In some cases, menhaden oil or a mixture of catfish oil and menhaden oil is used. It may be wise to restrict menhaden oil to no more than 1% of the diet.

Protein comprises about 70% of the dry weight of fish muscle. A continual supply of protein is needed throughout life for maintenance and growth. Catfish, like other animals, actually do not have a protein requirement, but they require a source of nonspecific nitrogen and indispensable amino acids. Usually the most economical source of these elements is a mixture of proteins in feedstuffs. Ingested proteins are hydrolyzed to release amino acids that may be used for synthesis of tissue proteins or, if in excess, used for energy. Use of protein for energy is expensive; thus, catfish feeds should be balanced to assure that adequate levels of nonspecific nitrogen, amino acids, and non-protein energy are supplied in proper proportions.

The requirements for proteins and their structural components, amino acids, have been studied in catfish for several years. Yet, there is still a debate as to which level of dietary protein provides for cost-effective growth. The level of dietary protein and amino acids needed for the most economical gain may differ as the cost of feed ingredients vary. In addition, it is difficult to set a level of protein that is optimum for all situations because of the factors that affect the dietary protein requirement of catfish. These include water temperature, feed allowance, fish size, amount of nonprotein energy in the diet, protein quality, natural food available, and management practices.

Most of the studies on protein requirements of catfish have been based on weight gain and feed efficiency. Data from those studies indicate that the dietary protein requirement for catfish ranges from about 25–50%. Recent studies have indicated that a protein level as low as 16% may be adequate for growout of food-sized catfish when the fish are fed to satiety. The rationale behind these studies is that the optimum dietary protein level is driven by economics as much as rate of gain. Thus, to maximize profits, the optimum dietary protein level should be changed as fish and feed prices change.

Although we speak of a protein requirement, it is more precise to formulate fish feeds based on amino acid requirements. Nutritionally, amino acids may be classified as either indispensable (essential) or dispensable (nonessential). An indispensable amino acid is one that the animal cannot synthesize or cannot synthesize in quantities sufficient for body needs; thus, they must be supplied in the diet. A dispensable amino acid is one that can be synthesized by the animal in quantities sufficient for maximal growth. Most simple-stomach animals, including catfish, require the same 10 indispensable amino acids (Table 4). There are differences in amino acid requirements among the various species of fish and other animals, but that is expected since the physiological needs for certain amino acids and the relative proportion of structural proteins may vary among species.

Dispensable amino acids can be synthesized by catfish, but there are certain advantages if they are provided in the diet. For example, if these amino acids are in the diet, energy is saved in their synthesis, and some dispensable amino acids can partially replace some indispensable amino acids (cystine can replace about 60% of the methionine, and tyrosine can replace about 50% of the phenylalanine). Practical catfish feeds contain liberal amounts of dispensable amino acids inherent in the proteins of various feedstuffs.

In a practical feed, amino acid requirements are best met by feeding a mixture of feedstuffs or by using a mixture of feedstuffs supplemented with amino acids. There has been much debate among fish nutritionists concerning the use of supplemental amino acids by fish. However, data indicate that amino acids are effectively used by catfish when supplemented into a practical feed. In practice, lysine (which is the first limiting amino acid in catfish feeds) is currently the only supplemental amino acid used in commercial catfish feeds.

Table 4. Amino acid requirements of catfish.

Amino acid	Requirement [1] (% of dietary protein)
Arginine	4.3
Histidine	1.5
Isoleucine	2.6
Leucine	3.5
Lysine	5.1
Methionine + cystine	2.3
Phenylalanine + tyrosine	5.0
Threonine	2.0
Tryptophan	0.5
Valine	3.0

[1]From National Research Council (1993). Nutrient Requirements of Fish. National Academy Press, Washington, D.C.

Vitamins

Vitamins are highly diverse in chemical structure and physiological function. They are generally defined as organic compounds that are required in small amounts in the diet for normal growth, health, and reproduction by one or more animal species. Some vitamins may be synthesized in the body in quantities sufficient to meet metabolic needs, and thus are not required in the diet.

Characteristic vitamin deficiency signs can be induced in catfish fed diets deficient in a particular vitamin, at least under experimental conditions (Table 5). Vitamin deficiencies are rarely encountered in natural populations of fish. Vitamin C and pantothenic acid deficiencies have been documented in commercially cultured catfish. The addition of sufficient levels of these vitamins to catfish feeds eliminated deficiency problems.

Qualitative and quantitative vitamin requirements for catfish have been well defined (Table 5). Vitamin requirements for catfish have generally been determined with small, rapidly growing fish. These values are considered to be sufficient to meet the needs of larger fish; however, vitamin requirements are affected by fish size, growth rate, stage of sexual maturity, diet

Table 5. Vitamin deficiency signs and minimum dietary levels required to prevent signs of deficiency in catfish.[1]

Vitamin	Deficiency signs	Requirement
A	Exophthalmia, edema, hemorrhagic kidney, skin depigmentation.	450-900 IU/lb
D	Low body ash, calcium, and phosphorus.	110-450 IU/lb
E	Muscular dystrophy, exudative diathesis, skin depigmentation, erythrocyte hemolysis, splenic and pancreatic hemosiderosis, fatty liver, ceroid deposition .	25 -50 ppm
K	Hemorrhagic skin.	R [4]
Thiamin	Loss of equilibrium, nervousness, dark skin color.	1 ppm
Riboflavin	Short-body dwarfism.	6 [2] - 9 ppm
Pyridoxine	Greenish-blue coloration, tenany, nervous disorders, erratic swimming.	3 ppm
Pantothenic acid	Clubbed gills, emaciation, anemia, eroded epidermis.	10-15 ppm
Niacin	Skin and fin lesions, exophthalmia, deformed jaws, anemia.	7.4 [3] - 14 ppm
Biotin	Hypersensitive, skin depigmentation, reduced liver pyruvate carboxylase activity.	R [4]
Folic acid	Anemia.	1.5 ppm
B_{12}	Anemia.	R [4]
Choline	Fatty liver, hemorrhagic kidney and intestine.	400 ppm
Inositol	Not demonstrated.	NR [4]
Ascorbic	Scoliosis, lordosis, internal and external hemorrhage, fin erosion, reduced bone collagen formation.	11-60 ppm

[1]Requirements and deficiency signs are based on the following references with new information added: Robinson E.H, 1989, Channel catfish nutrition, Reviews in Aquatic Sciences 1:365-391 and National Research Council, 1993; Nutrient Requirements of Fish, National Academy Press, Washington, D.C. Anorexia, reduced weight gain, and mortality are not listed as deficiency signs since they are common vitamin deficiency signs.
[2]From Serrini, G., Z. Zhang, and R.P. Wilson, 1996, Dietary riboflavin requirement of fingerling channel catfish, Aquaculture 139:285-290.
[3]From Ng, W.K., G. Serrini, Z. Zhang, and R.P. Wilson, 1997, Niacin requirement and inability of tryptophan to act as a precursor of NAD^+ in channel catfish, Aquaculture 152: 273-285.
[4]R and NR refer to required and not required, respectively.

formulation, disease, and environmental conditions. The interrelationships among these factors and the vitamin needs of fish have not been adequately defined.

Catfish feeds are generally supplemented with a vitamin premix that contains all essential vitamins in sufficient quantities to meet the requirement and to compensate for losses due to feed processing and storage. Vitamin losses during storage are not a major factor in the Mississippi Delta and other places where feed is generally not stored for more than 2–3 days.

Vitamins present in feedstuffs have usually not been considered during feed formulation because their bioavailability is not known. New data have indicated that vitamins inherent in dietary ingredients make a significant contribution to the vitamin nutrition of pond-raised catfish. Natural food organisms may also be a source of vitamins for catfish. Zooplankton collected from commercial catfish ponds contain all vitamins, some in relatively high concentrations (see “Natural Foods” under “Feeding”). Although many nutritionists discount the contribution of natural foods to the nutrition of catfish, we have data that indicate that these foods may contribute to the micronutrient requirements of catfish.

We have conducted several studies on the growout of catfish in earthen ponds in which the fish were fed diets with and without supplemental vitamins. Results from these studies have consistently indicated no differences in any parameter measured. This is not to imply that supplemental vitamins are not needed in catfish diets. However, it may be that the concentrations of certain vitamins can be reduced or that certain vitamins can be removed from the vitamin premix without affecting fish performance. Studies are currently under way to determine practical vitamin requirements for catfish. Composition of vitamin premixes currently recommended for use in practical catfish feeds are discussed in “Feed Ingredients” under “Feeds.”

There has been considerable interest among catfish producers and researchers concerning the use of megadose levels of certain vitamins, particularly vitamin C, to enhance disease resistance in catfish. Early evidence indicated that high levels of vitamin C (10 times or more than the level needed for normal growth) reduced mortality caused by certain bacterial diseases that affect catfish. Consequently, some catfish producers fed a high-C feed, which contained about 2,000 parts per million (ppm) vitamin C, during late winter or early spring, presumably to enhance the immune system of catfish. More recent results from at least six studies show no benefits of using high levels of dietary vitamin C for increasing resistance to enteric septicemia of catfish (ESC). Data from these studies indicate that catfish response to dietary vitamin C during ESC challenge is basically an “all or none” type of response. That is, if vitamin C is not present, then mortalities are increased during ESC challenge; however, if vitamin C is present in the diet, mortalities are significantly reduced. Concentrations as low as 25 ppm vitamin C have been shown to enhance survival of catfish during challenge with the bacterium *E. ictaluri*. There is evidence that the vitamin C requirement of catfish for normal growth is as low as 15 ppm. Commercial catfish feeds manufactured in the Mississippi Delta generally contain about 50–100 ppm vitamin C in the final feed, which is sufficient for optimum growth and health of the fish. High doses of dietary vitamin E do not appear to improve disease resistance of catfish to ESC.

Minerals

Catfish apparently require the same minerals for metabolism and skeletal structure as other animals require. Catfish also require minerals for osmotic balance between body fluids and their environment; some of these minerals can be absorbed from the water. Minerals may be classified as macrominerals or microminerals, depending on the amount required in the diet. Macrominerals are required in relatively large quantities, and microminerals are required in trace quantities. Mineral nutrition studies with fish are complicated by dissolved minerals found in the water. For example, a dietary calcium requirement can only be demonstrated in catfish reared in calcium-free water. In water containing sufficient calcium, catfish can meet their calcium requirement by absorption of calcium from the water. Fourteen minerals are considered essential for catfish. Although mineral studies with fish are difficult to conduct, deficiency signs and quantitative requirements for macro- and microminerals have been determined for catfish (Table 6).

Among macrominerals, phosphorus is particularly important in fish feeds because fish require a relatively large quantity of the mineral in the diet. Feedstuffs — especially those of plant origin — are poor sources of biologically available phosphorus, and fish do not obtain significant amounts of phosphorus from pond water. Therefore, catfish feeds are usually supplemented with phosphorus. Dicalcium and defluorinated phosphates are commonly used as phosphorus supplements in catfish feeds. Catfish growth data from both laboratory and pond studies have indicated that defluorinated phosphates had essentially the same nutritional value as dicalcium phosphate.

Approximately two-thirds of phosphorus in feedstuffs of plant origin is in the form of phytate, a bound form of phosphorus that is poorly available to fish. Studies have demonstrated that phytase enzymes can be used in animal feeds (including catfish) to release phytate phosphorus, thus making it available for absorption.

Catfish feeds are typically supplemented with a trace mineral premix that contains all essential trace minerals in sufficient amounts to meet or exceed dietary requirements of catfish (mineral composition of trace mineral mix is discussed in “Feed Ingredients” under “Feeds”). However, there is evidence that supplemental trace minerals are not needed, particularly in diets containing animal proteins.

Table 6. Mineral deficiency signs and minimum dietary levels required to prevent deficiency signs in catfish.[1]

Mineral	Deficiency signs	Requirement
Ca [2]	Reduced bone ash	None
P [3]	Reduced bone ash, Ca, and P	0.3-0.4%
Mg	Sluggishness, muscle flaccidity, reduced body Mg	0.02 [4] - 0.04%
Na	ND [5]	ND
K [6]	None	0.26%
Cl	ND	ND
S	ND	ND
Co	ND	ND
I	ND	ND
Zn [7]	Reduced serum zinc and serum alkaline phosphatase activity, reduced bone zinc and calcium concentrations	20 ppm
Se	Reduced liver and plasma selenium-dependent glutathione peroxidase activity	0.25 ppm
Mn	None	2.4 ppm
Fe	Reduced hemoglobin, hematocrit, erythrocyte count, reduced serum iron and transferrin saturation levels	20 ppm
Cu	Reduced heart cytochrome c oxidase, reduced hepatic Cu-Zn superoxide dismutase activities	4.8 ppm

[1]Requirements and deficiency signs are based on the following references with new information added: Robinson E.H, 1989, Channel catfish nutrition, Reviews in Aquatic Sciences 1:365-391; and National Research Council, 1993, Nutrient Requirements of Fish, National Academy Press, Washington, D.C. Anorexia, reduced weight gain, and mortality are not listed as deficiency signs since they are common mineral deficiency signs. Minerals listed as not determined are assumed to be required.
[2]Deficiency cannot be demonstrated in catfish reared in water containing sufficient calcium.
[3]Requirement expressed on an available basis.
[4]From Lim, C., and P.H. Klesius, 1999, Influence of dietary levels of magnesium on growth, tissue mineral content and resistance of channel catfish challenged with *Edwardsiella ictaluri*, 27th Fish Feed and Nutrition Workshop, Portland, Oregon (Abstract).
[5]ND = not determined.
[6]From Wilson, R.P., and G. El Naggar, 1992, Potassium requirement of fingerling channel catfish, Aquaculture 108:169-175. Requirement based on whole body potassium balance.
[7]Requirement will increase in presence of phytic acid.

Nonnutritive Dietary Components

Toxins

Various toxins may occur in feeds or feed ingredients and have the potential to cause morbidity, mortality, or loss of productivity among cultured catfish. Included among these are chemical compounds that occur naturally in feed ingredients and mycotoxins that develop as a result of mold infestation. Chemical compounds can exert their effect on catfish by being explicitly toxic or in an indirect manner by inhibiting digestion and absorption of nutrients. Usually, a detectable decline in growth rate is the first response an animal suffers after consuming feeds that contain these toxic substances at levels that do not cause immediate mortality. Thus, reduced growth is a very sensitive indicator of exposure to toxins, but it is nonspecific in that exposure to many undesirable factors can elicit the same response. After continued feeding of the toxin, other changes in the animal’s physiology, morphology, and biochemical processes will take place, including reduced hematocrit, elevation in serum and liver enzyme values, the appearance of neoplastic growths, and altered biochemical pathways that result in the accumulation of tissue metabolites.

Endogenous Toxins of Feed Ingredients

Endogenous toxins are substances found in a feed ingredient as the normal array of compounds that are associated with the ingredient. Consumption of these toxins at harmful levels may result in impaired digestion and absorption of nutrients, altered metabolic mechanisms, and changes in organ morphology.

Trypsin Inhibitors. Trypsin inhibitors are components of the seeds of many legume plants, of which soybeans are the most important to the catfish industry. It has been known for many years that soybeans contain a protein that can form irreversible complexes with the pancreatic enzyme trypsin and essentially inactivate its proteolytic activity. Under proper conditions, heat processing of flaked soybean denatures the problematic protein and inactivates its trypsin inhibition properties. Heating soybean meal must be done under carefully controlled conditions; underheating will allow sufficient trypsin inhibitor to remain, causing reduced feed utilization. However, overheating soybean meal will reduce the availability of some amino acids, such as lysine, due to formation of lysine-carbohydrate complexes.

Phytic Acid. Approximately 70% of the phosphorus in seeds is stored in the form of phytate-phosphorus, which is largely unavailable to simple-stomach animals like the catfish. In addition to reducing the availability of phosphorus, phytate can also chelate with and reduce the bioavailability of other minerals such as zinc, manganese, copper, molybdenum, calcium, magnesium, and iron. A commercial preparation of the enzyme phytase can effectively improve utilization of phytate-phosphorus in catfish diets.

Gossypol. This poisonous yellow pigment is associated with cottonseed and processed cottonseed meal. It may be found in amounts large enough to adversely affect the growth of catfish fed diets containing high levels of cottonseed meal. Dietary levels of free gossypol above 900 ppm have been shown to inhibit the growth of catfish.

Cyclopropenoic Fatty Acids. Cottonseed meal contains another group of toxic compounds referred to as cyclopropenoic fatty acids (CFAs), primarily sterculic acid and malvalic acid. The effect of CFAs on catfish has not been evaluated, but use of cottonseed meal in practical catfish diets at levels of 30% or less does not appear to affect catfish performance or cause liver abnormalities.

Glucosinolates. These inert compounds found in rapeseed are activated by the enzyme myrosinase, which is released when the seed coat of rapeseed is broken in a process such as grinding. These compounds impair thyroid activity by interfering with thyroidal ability to uptake and bind iodine. The effects of these compounds, with the exception of goitrins, can be reversed by dietary iodine supplementation. The levels of glucosinolates in rapeseed have been greatly reduced with the development of rapeseed cultivars known as “canola.”

Erucic Acid. Another toxic component of rapeseed, erucic acid is a C22:1 n-9 fatty acid. Selective breeding of rapeseed to produce low-erucic-acid “canola” has reduced erucic acid content from 25–55% in rapeseed oil to less than 2% in canola oil. The toxic effects of erucic acid have not been evaluated in catfish. Levels of 3–6% pure erucic acid in the diet cause mortality and pathologies of skin, gill, kidney, and heart in salmonids. However, levels of erucic acid in rapeseed meal do not appear to be high enough to cause pathologies in fish.

Mycotoxins

Interest in the effects that mycotoxins have on catfish productivity and health has increased in the past decade. A common mycotoxin, aflatoxin, is produced by the mold *Aspergillus flavus* and is often found on catfish feed ingredients such as corn and cottonseed meal. The United States Food and Drug Administration (FDA) imposed a 20-part-per-billion (ppb) limit on aflatoxin contamination in food for humans and feed for animals. This upper limit has been modified several times to permit higher levels of aflatoxin in feeds designated for certain classes of livestock and poultry.

Catfish appear to tolerate high levels of aflatoxin. A laboratory study conducted at Auburn University in Alabama showed that catfish fed a diet containing 2,100 ppb pure aflatoxin caused no mortalities, reduction in growth rate, or histological changes in liver tissues. At an inclusion level of 10,000 ppb, there was a reduction in growth rate and hematocrit values, along with minor histological changes in cellular morphology of liver and kidney tissues. A long-term feeding study conducted in ponds at the Thad Cochran National Warmwater Aquaculture Center (NWAC) in Stoneville, Mississippi, showed that a diet containing 50% aflatoxin-contaminated corn (88 ppb aflatoxin in the diet) had no effect on weight gain, feed conversion, hematocrit values, and liver morphology of catfish.

Research has demonstrated that mycotoxins produced by members of the *Fusarium* genus can be toxic to catfish. Fumonisin B_1 (FB_1), moniliformin, deoxynivalenol (DON), and T-2 toxin are among the *Fusarium*-produced mycotoxins that have been tested on catfish. All have been shown to negatively affect the growth of catfish fingerlings. These mycotoxins have been found to contaminate grains such as corn, wheat, and milo that are infected with certain species of *Fusarium* molds. Infection of grains usually occurs in the field, but mycotoxin concentration may increase during storage under improper conditions.

Small catfish fingerlings appear to be sensitive to FB_1 at levels of 20 ppm and above in a practical diet containing FB_1-contaminated culture material. The toxicity of moniliformin has been studied with catfish recently and determined to cause a reduction in weight gain at 20 ppm in 1.5-gram fish. Deoxynivalenol, one of the *Fusarium* trichothecene mycotoxins, has been fed to catfish as the pure mycotoxin in a laboratory study at the NWAC. The results after 8 weeks of feeding demonstrated that pure DON at dietary levels up to 10 ppm produced no significant reductions in body weight gains or feed consumption in 6.8-gram catfish. This finding contrasts the response of other animals such as pigs, dogs, and rainbow trout, which experience a loss of appetite at levels of DON of 1 to 3 ppm. A laboratory study is ongoing to evaluate the effect of DON-contaminated wheat on catfish.

T-2 toxin, another trichothecene mycotoxin, was added in pure form to a chemically defined diet composed of casein, gelatin, and dextrin in an 8-week aquarium study at the NWAC. The results demonstrated that T-2 toxin is much more toxic to catfish than DON. Levels of T-2 toxin of 0.625 ppm or above produced significant reductions in weight gain. The *Fusarium* organism that produces T-2 toxin tends to favor wheat as its substrate, and wheat or wheat by-products are common ingredients in catfish feed. Therefore, there is potential for T-2 toxicity to occur under catfish aquacultural conditions.

Mycotoxins pose both a challenge and a risk to catfish feed producers and farmers. The mold organisms that produce these toxins are ubiquitous. Under conditions ideal for mold development, elaboration of mycotoxins can occur on feed ingredients and catfish feeds. Since catfish feeds usually contain up to 85–90% plant ingredients, including corn, wheat, wheat by-products, and soybean meal, there is ample opportunity to incorporate ingredients that may contain one or more mycotoxins at harmful concentrations. It is important to screen these ingredients for suspected mycotoxin contamination before using them in feed manufacture.

Fiber

Fiber is a nonnutritive component of catfish diets. Animals with a digestive system consisting of only a single gastric stomach cannot derive any direct nutritional benefit from the consumption of dietary fiber. Such is the case with catfish and some land animals, such as chickens. In these cases, fiber provides bulk to the ingesta and may alter transit time of ingested material within the gut lumen. The usual approach to formulating diets for simple-stomach animals is to use ingredients that will maintain dietary fiber levels below acceptable maximum levels. These levels would be in the range of 3–6% crude fiber for catfish diets.

Fiber content of catfish diets includes those organic components of the dietary ingredients that are indigestible in normal digestive processes. These components include cellulose, lignin, hemi-cellulose, and other insoluble, complex carbohydrates of plant origin. It does not include soluble, complex plant carbohydrates such as pectin and other vegetable gums, because soluble dietary fiber is not recovered in the analysis of crude fiber.

Catfish feeds that contain levels of fiber above the desirable range will increase the amount of waste material deposited in the pond. Accumulations of waste material on the pond bottom may deteriorate water quality since their degradation depletes dissolved oxygen. To minimize this effect, ingredients that contain high levels of crude fiber should be restricted to lower levels of inclusion or should not be included at all.

Pigments

Pigments are possible nonnutritive components of catfish diets. A limited amount of pigmentation can occur in catfish flesh because of the consumption of certain oxygenated carotenoid compounds (xanthophylls). This pigmentation is considered undesirable. The main xanthophylls in catfish feeds — lutein and zeaxanthin — come from corn. Catfish flesh usually has a desirable pale, light color when the feed ingredients do not contain high concentrations of xanthophyll compounds. High-xanthophyll ingredients include by-products of corn wet-mill processing such as corn gluten meal. If corn gluten meal is used in conjunction with the corn that is typically found in catfish feeds, it is likely that the fillets will have an objectionable yellow color. Usually, the xanthophyll content must exceed 11 ppm for this to occur. Comparison of the xanthophyll content of corn (10–20 ppm) and corn gluten meal (330 ppm) shows that it is important not to include corn gluten meal in catfish growout feeds. Use of even 5% of this ingredient in conjunction with 30% corn would add more than 20 ppm xanthophyll to the feed.

Feed Additives

Additives to catfish feeds are used to improve the quality and performance of the feed. Additives include pellet binders, antioxidants, and antibiotics.

Pellet Binders

Pellet binders are added to catfish feeds to improve the quality of steamed pellets. These products increase the durability of pellets and improve their stability in water. Improvement of pellet durability decreases the amount of fines generated through normal handling. It also increases water stability, which extends the time pellets remain intact after feeding. Both characteristics help improve water quality and feed conversion. Pellet binders are materials that help hold feed ingredients of the proper particle size together. They are activated by heat and pressure applied during the pelleting process. Practical pellet binders include the bentonites, which are clay compounds mined from deposits in the western United States, and lignin sulfonates, which are by-products of the wood processing industry. Both of these binders have demonstrated effectiveness as pellet binders for feeds used in aquaculture. Neither adds any nutritional value to catfish feeds. Gluten contained in wheat is also a good pellet-binding agent, which has the added benefit of providing nutritional value to catfish. Extruded catfish feeds do not require additional pellet binder; these feeds must be composed of at least 25% grain or grain by-products for proper gelatinization and expansion.

Antioxidants

Antioxidants are compounds that retard the oxidation of certain nutrients. In some cases, nutrients themselves function in the capacity of biological antioxidants; examples of these include vitamins C and E. Nutrients protected by antioxidants include polyunsaturated lipids and fat-soluble vitamins A and D. Destruction of the fat-soluble vitamins and polyunsaturated fatty acids occurs as a result of the lipid peroxidative process known as oxidative rancidity. During this process, polyunsaturated lipids generate free radicals of oxygen, which are very reactive and destroy nutrients. Prevention of peroxide formation can be accomplished by including synthetic antioxidants in catfish feeds. The synthetic antioxidants used in animal feeds are BHA (butylated hydroxianisole), BHT (butylated hydroxytoluene), and ethoxyquin. These compounds may be added to fats or directly to feeds at mixing. Usually, the antioxidants are incorporated in the supplemental fat or oil that is sprayed on catfish feeds. FDA-permissible levels for BHA and BHT are 0.02% of dietary fat content; for ethoxyquin, 150 ppm.

Antibiotics

Only a limited number of FDA-approved antibiotics are available for controlling bacterial diseases of catfish. Because the catfish industry is relatively new and involves what is classified as a minor species, drug companies have been reluctant to develop new antibiotics for catfish. The two antibiotics presently available to catfish producers are oxytetracycline (Terramycin®, Philbro Animal Health, Fort Lee, New Jersey) and a combination of sulfadimethoxine and ormetoprim usually referred to by its commercial name, Romet® (Alpharma, Inc., Animal Health Division, Fort Lee, New Jersey). These antibiotics are incorporated into feeds to be fed to catfish diagnosed with specific diseases. The use of these antibiotics is described in "Feeding Diseased Fish" under "Feeding."

FEEDS

Although natural food organisms may provide certain nutrients (particularly micronutrients such as vitamins and fatty acids), the contribution of pond organisms to the nutrition of intensively cultured catfish is generally considered to be small. Thus, the nutritional requirements of cultured catfish are met by using a complete feed — that is, a feed formulated to provide all required nutrients in the proper proportions necessary for rapid weight gain, high feed efficiency, and a desirable composition of gain (i.e., high protein gain and low fat gain). Feed cost represents about one-half of variable production costs in catfish culture; thus, careful consideration should be given to feed selection and use.

Feed Ingredients

No single feed ingredient can supply all of the nutrients and energy required for optimum growth of catfish. Thus, commercial catfish feeds contain a mixture of feedstuffs and vitamin and mineral premixes that provide adequate amounts of essential nutrients, as well as the energy necessary for their utilization. The amount of each feed ingredient used depends on several factors including nutrient requirements, ingredient cost, availability of each ingredient, and processing characteristics. The effects of feedstuffs on feed manufacturing are discussed under "Feed Manufacture."

Protein Supplements

Feedstuffs containing 20% crude protein or more are considered protein supplements. Protein supplements may be classified as animal or plant proteins. Animal proteins used in animal feeds come from inedible tissues from meatpacking or rendering plants, milk products, and marine sources. Those typically used in catfish feeds include fish meal, meat and bone meal, and blood meal. Animal proteins are generally considered to be of higher quality than plant proteins, primarily because of their superior complement of indispensable amino acids. Animal protein is essential in the diet of fry and small fingerling catfish. Fish meal prepared from whole fish appears to be a better protein supplement than other animal proteins. Fish meal does not appear to be essential in the diet of catfish after they reach a size of 6–7 inches. Fish meal can be completely replaced by combinations of meat and bone meal or meat and bone/blood meal in diets for food-fish growout. There is also evidence that animal proteins can be completely replaced by plant proteins in food-fish growout feeds without affecting growth and feed efficiency.

The primary plant protein sources used in catfish feeds are oilseed meals, such as soybean meal, cottonseed meal, and peanut meal. Certain other oilseed meals could be used, but they are not generally available on a timely basis and at an economical cost per unit of protein. Compared with animal proteins, most plant proteins are deficient in lysine and methionine, the two limiting amino acids in catfish feeds. In addition, certain plant proteins contain toxins and antinutritional factors that may or may not be inactivated during processing of the meal. A brief description of various animal and plant protein sources that can be used in catfish feeds is given in Table 7.

Fish Meal. Fish meal is prepared from dried, ground tissues of undecomposed, whole marine fish or fish cuttings such as menhaden, herring, or white fish. Fish meal contains 60–80% protein of excellent qual-

Table 7. Feed ingredients used in commercial catfish feeds.[1]

Feed ingredient	Selected characteristics (%)						Comments
	Dry Matter	Crude protein	Crude fat	Crude fiber	Lys.	Met.+ Cys.	
Protein Supplements							
Soybean meal (dehulled, solvent-extracted)	89.3	48	1	3	3.2	1.5	Major protein source in feeds. A high-quality ingredient. Contains antinutritional factors destroyed by heating. Palatable to catfish.
Cottonseed meal (direct solvent-extracted)	90.4	41	2.1	11.3	1.76	1.1	Used sparingly. Up to 20% can be used without detriment. More can be used if supplemented with lysine. Highly palatable. Contains free gossypol, which can be toxic. Feeds with < 0.09% free gossypol not detriment al. Deficient in lysine; lysine availability reduced by binding to free gossypol.
Peanut meal (mechanically extracted)	91.8	45	5	12	1.55	1.1	Deficient in lysine. Levels used in catfish feed restricted to about 15-20% without lysine supplementation.
Fish meal [2] (Menhaden)	92	62	10.2	1	4.7	2.4	Good source of indispensable amino acids, phosphorus, and digestible energy. May also provide essential fatty acids. Highly palatable to catfish. Growout feeds for catfish generally contain 2 -4% fish meal.
Meat and bone meal	92.6	50	8.5	2.8	2.6	1	Good source of calcium and phosphorus. High in ash, which limits its use somewhat because of possibility of mineral imbalances. Maximum level recommended for catfish feeds is 15%.
Blood meal	91	85	1	1	6.9	1.6	Flash or spray-dried blood meals have been used. Excellent source of lysine but deficient in methionine. Up to 5% can be used as lysine supplement. Generally used in combination with meat meals.
Catfish offal meal	90	58	11	–	4.19	1.9	Prepared from catfish processing waste. Good source of calcium, phosphorus, and energy. Use depends on availability.
Full-fat soybeans	90	38	18	5	2.4	1.1	Rarely used in catfish feeds, primarily because of high fat content. A limited amount can be used if total fat level in feed does not exceed about 6%.
Energy supplements							
Corn grain [3] (yellow)	88	8.9	3.5	2.9	0.22	0.3	Abundant and relatively inexpensive source of energy. Cooking improves energy digestibility. Aids in pelleting and improves floatability of feed.
Wheat gain	88	13.5	1.9	3	0.4	0.6	Generally used sparingly in catfish feeds because corn is less expensive. Used at rate of 3-4% to improve binding of feed pellet.
Wheat middlings	89	17.7	3.6	7	0.6	0.3	Used at levels up to 15-30% in some catfish feeds. Improves pellet binding. Nutritional value at least as good as corn and wheat grain.
Rice bran	91	13.5	12.5	13	0.5	0.3	Used at low levels (3-5%) because of high fat and fiber levels.
Catfish oil	–	–	100	–	–	–	Fat extracted from processing waste. About 1-2% sprayed on top of finished feed. Good energy source. Used to reduce feed dust.
Fish oil	–	–	100	–	–	–	Good source of essential fatty acids and energy. Also used to reduce feed dust by spraying on finished feed pellet. Used at a rate of < 2%. May reduce survival of fish exposed to ESC.
Fat	99.5	–	99.4	–	–	–	Generally highly digestible. May not supply essential fatty acids. Spray on top of finished feed at rate of 1-2% to reduce feed dust.
Vitamin Supplements							
Vitamin premix	–	–	–	–	–	–	Meet recommendations given in Table 8.
Mineral Supplements							
Mineral premix	–	–	–	–	–	–	Meet recommendations given in Table 8.
Dicalcium or defluorinated Phosphates	–	–	–	–	–	–	Used as a phosphorus source at a rate of 1-1.5%. Phosphorus from these sources is about 80% digestible to catfish.
Pellet binders [4]	–	–	–	–	–	–	Generally, natural binders in grains sufficient for extruded feeds. Some feed manufacturers add about 2-2.5% processed milo as a binder in extruded feeds. Various binders have been used in pelleted (sinking) feeds, including lignosulfonates, bentonites, and processed milo.

[1]Adapted from Robinson, E.H., 1990. Feed, feed processing, and feeding of catfish. Technical Bulletin, Takeda, Inc.
[2]Other fish meals may be used.
[3]Corn screenings and corn grain are often used interchangeably.
[4]If processed milo is used as a binder, it has nutritive value of milo grain.

ity, which is highly palatable to catfish. Since fish meal is a good source of essential amino acids, it is often used to supplement feeds containing plant proteins. Fish meal is also rich in energy, minerals, and essential fatty acids. It is used at levels up to 50% in catfish fry feeds, up to 12% in catfish fingerling feeds, and from 0–8% in food-fish growout feeds.

Meat and Bone Meal. Meat and bone meal is the rendered product from beef or pork tissues and should not contain blood, hair, hoof, horn, hide trimmings, manure, stomach and rumen contents, except in amounts as may be unavoidable during processing. Meat and bone meal contains approximately 50% crude protein. Its protein quality is inferior to whole fish meal, because it contains less lysine and the consistency of the product may vary considerably. Although it is a good source of minerals, its high ash content may limit its use because of possible mineral imbalance. The maximum level of meat and bone meal recommended for catfish feeds is 15%.

Blood Meal. Blood meal is prepared from clean, fresh animal blood, excluding hair, stomach belchings, and urine except in trace quantities that are unavoidable. It contains 80–86% crude protein and is an excellent source of lysine. It is deficient in methionine. Levels up to 5% can be used in catfish feeds.

Meat and Bone/Blood Meal Blend. A mixture of meat and bone meal and blood meal is blended in certain proportions to give the desired nutritional characteristics. Generally, the blend mimics the nutritional profile of menhaden fish meal and provides 60–65% protein. The blended products are an excellent protein source for use in catfish feeds and are generally used to replace fish meal.

Catfish Offal Meal. Catfish offal meal is prepared from catfish processing waste, primarily heads, frames, and visceral organs (after the oil has been removed). The product contains approximately 58% protein. It is of better nutritional quality than meat and bone meal but not as good as menhaden fish meal. It is highly palatable to catfish; however, it is seldom used in catfish feeds because it is not available in adequate amounts throughout the growing season.

Poultry By-Product Meal. Poultry by-product meal is made up of ground, rendered or clean parts of the carcass of slaughtered poultry. It contains heads, feet, underdeveloped eggs, and visceral organs, but it does not contain feathers. The product contains approximately 65% good-quality protein, but it is seldom used in catfish feeds because it is not available on a regular basis at a reasonable cost per unit of protein.

Hydrolyzed Poultry Feathers. Hydrolyzed poultry feathers are prepared by using pressure to treat clean, undecomposed feathers from slaughtered poultry. At least 75% of the protein should be digestible as measured by pepsin digestion. It is high in protein (85%), but protein quality is not as good as other animal protein sources. Although amounts up to 5–10% can be used catfish feeds, hydrolyzed poultry feathers are rarely used.

Soybean Meal. Soybean meal is prepared by grinding the flakes after solvent extraction has been used to remove the oil from dehulled soybeans. Dehulled, solvent-extracted soybean meal contains 48% protein and is the predominant protein source used in catfish feeds. It has the best amino acid profile of all common plant protein sources and is highly palatable and digestible to catfish. Antinutritional factors are destroyed or reduced to insignificant levels with heat that is applied during the extraction process. Levels of soybean meal up to 50% have been used in commercial catfish feeds without detrimental effect.

Heated, Full-Fat Soybean Meal. Full-fat soybean meal is prepared by grinding heated soybeans that have not undergone the oil extraction process. The meal contains 39% protein and 18% fat. It is rarely used in catfish feeds because of its high fat content. A limited amount can be used in catfish feeds as long as the total fat level in the finished feed does not exceed about 6%.

Cottonseed Meal. Cottonseed meal is obtained by grinding the cake remaining after the oil has been solvent extracted. The product generally contains 41% protein but must not contain less than 36% protein. It is highly palatable to catfish but is deficient in lysine. Cottonseed meal contains free gossypol and cylcopropenoic acids, which can be toxic. However, levels of these chemicals in commonly available cottonseed meal are generally well below toxic levels. Levels of cottonseed meal should not exceed 30% of catfish feed unless supplemental lysine is used. Cottonseed meal is generally used in catfish feeds at a level of 10–15%.

Peanut Meal. Peanut meal is obtained by grinding shelled peanuts after the oil has been removed mechanically or by solvent extraction. Solvent-extracted peanut meal contains 48% protein, and the mechanically extracted product contains 45% protein. Peanut meal is highly palatable to catfish and contains no known antinutritional factors, but it is deficient in lysine. Levels used in catfish feeds are restricted to 15–20% without lysine supplementation. Peanut meal is seldom used in catfish feeds because of its sporadic availability.

Distillers' Dried Grains with Solubles. These supplements are the primary residues after removal of the alcohol by distillation from the yeast fermentation of cereal grains. The product contains approximately 27% protein and is highly palatable to catfish. Levels up to 25–30% can be used in catfish feeds. If higher levels are used, supplemental lysine may be needed.

Sunflower Meal. Sunflower meal is prepared by grinding the residue remaining after mechanical or solvent extraction of the oil from sunflower seeds. Dehulled sunflower meal is prepared from sunflower seeds after the hull is removed. Solvent-extracted sunflower meal contains about 44% protein. The hulls are not easily removed, so even dehulled sunflower meal contains around 13% fiber. Higher levels of fiber are found in meals that are not dehulled. Sunflower meal can be used in catfish feeds to replace part of the soybean meal. Its low-lysine content and high level of fiber limit its usefulness in catfish feeds. A level of up to 20% without lysine supplementation is acceptable for catfish feeds.

Canola Meal. Canola meal is prepared from a special rapeseed after solvent extraction to remove the oil. Compared with typical rapeseed meal, canola meal is low in glucosinolates and erucic acid, which may be detrimental to fish growth. Canola meal contains about 38% protein and is relatively low in lysine as compared with soybean meal. However, lysine content in canola meal is higher than other oilseed meals. It is palatable to catfish and can be used at levels up to about 20–25% without supplemental lysine. It is seldom used in catfish feeds because of lack of availability.

Energy Supplements

Energy supplements are feedstuffs that contain less than 20% crude protein. These include grain and grain by-products, and animal fat or vegetable oil. Energy sources typically used in commercial catfish feeds include corn, corn screenings, wheat grain, wheat middlings, rice bran, milo, animal fat, and fish oil.

Corn Grain and Corn Screenings. Corn and corn screenings are used interchangeably in commercial catfish feeds as a relatively inexpensive source of energy. Corn screenings are obtained in the cleaning of corn and include light and broken corn grain. Cooking improves energy digestibility of corn for catfish. The digestible energy value of corn grain and corn screenings for catfish is about 1,150 kcal per pound.

Wheat Grain. Wheat is a good source of energy for catfish, but it is generally more expensive than corn. Consequently, wheat grain has been used sparingly (2–5%) in catfish feeds, primarily for its pellet-binding properties. Wheat grain has a digestible energy value of about 1,160 kcal per pound for catfish.

Wheat Middlings. Wheat middlings are fine particles of wheat bran, shorts, germ, and flour recovered from milling wheat grain. Depending on cost, wheat middlings are used to replace corn or corn screenings in catfish feed and are routinely used at levels up to about 25%. In humid areas such as the Mississippi Delta, using levels greater than 25% may cause the feed to become sticky, resulting in clumping of feed pellets and handling problems. Low levels (2–5%) are often used to improve pellet binding. Wheat middlings have a digestible energy value of about 950 kcal per pound for catfish.

Rice Bran. Rice bran is the bran layer and germ of rice grain, including only the hulls or broken rice that are unavoidable in milling rice grain. It is high in fat and fiber, which limits its use in catfish feeds. Rice bran can be used in catfish feeds at levels of 3–5%. Rice bran has a digestible energy value of about 970 kcal per pound for catfish.

Milo. Milo is chemically similar to corn but somewhat higher in protein (11%). Milo is generally substituted for corn on weight-for-weight basis in catfish feeds. Energy value is assumed to be about the same as corn for catfish. When milo is substituted for corn, the feed is darker and more dense. Some varieties have a high tannin concentration in seed coat and are not as palatable for certain animals. There are some unverified reports of decreased palatability when milo is substituted for corn in catfish feeds. Research with catfish conducted at the DBES did not demonstrate a difference in performance of catfish fed feeds containing either corn or milo.

Corn Gluten Feed. Corn gluten feed is the part of corn remaining after the extraction of most of the starch and gluten by the process of wet milling of cornstarch to produce ethanol and syrup. It is a potential energy source for catfish feeds. This product typically contains about 18–20% crude protein and 10% fiber, and it is usually competitively priced relative to corn and wheat middlings. Up to 50% of corn gluten feed can be used

Table 8. Nutrients recommended for catfish growout feeds.

Nutrient	Recommended level [1]	Comments
Protein (%)	26-32	Varies depending on fish size, water temperature, dietary energy level, and daily feed allowance.
Essential amino acids (% of protein):		
Arginine	4.3	Generally, if lysine and sulfur-containing amino acid requirements are met, other amino acids will be adequate with feedstuffs commonly used in catfish feeds. Cystine can replace about 60% of methionine requirement. Tyrosine can replace about 50% of phenylalanine requirement. Synthetic amino acids can be used to supplement deficient proteins.
Histidine	1.5	
Isoleucine	2.6	
Leucine	3.5	
Lysine	5.1	
Methionine	2.3	
Phenylalanine	5.0	
Threonine	2.0	
Tryptophan	0.5	
Valine	3.0	
Digestible energy (kcal/g protein)	8.5–10	Use carbohydrate and lipid (fats or oils) as energy to spare protein for growth.
Lipid (%)	4–6	Mixture of animal, vegetable, and fish oils may be used. High levels of marine fish oil may impart a “fishy” flavor to the fish. Supplemental fat or oil should be sprayed on pellet surface.
Carbohydrate (%)	25–35	Floating feeds require at least 25% grain. Use grain byproducts for good expansion and bonding. Crude fiber should be maintained below 7%.
Vitamins:		
A	1,000 IU/lb	Acetate ester is used to improve stability during feed processing.
D_3	500 IU/lb	D-activated animal sterol used as source of D_3.
E	30 ppm	DL-alpha-tocopheryl acetate used for improved stability.
K	4.4 ppm	Required, but level for catfish not known. Menadione sodium bisulfite used to ensure adequacy.
Thiamin	2.5 ppm	Thiamin mononitrate generally used.
Riboflavin	6 ppm	
Pyridoxine	5 ppm	Pyridoxine HCl generally used.
Pantothenic acid	15 ppm	Calcium d-pantothenate generally used.
Nicotinic acid	None	Required, but feed contains adequate nicotinic acid without adding a supplement.
Biotin	None	Required, but feed contains adequate biotin without adding a supplement.
Folic acid	2.2 ppm	
B-12	0.01 ppm	Required, but amount not known. Synthesized in intestine of catfish.
Choline	None	Required in low-methionine diets. Abundant in most feedstuffs; supplements apparently not necessary.
Inositol	None	No requirement demonstrated.
Ascorbic acid	50 [2] ppm	Phosphorylated form stable during feed processing and storage. Metabolized forms lose 40-60% of activity during processing.
Minerals:		
Calcium	None	Catish usually absorb sufficient calcium from water. Requirement of 0.45% in calcium-free water.
Phosphorus, available	0.3–0.35%	About 33% of plant phosphorus and about 50-70% of animal phosphorus available to catfish. Dicalcium or defluorinated phosphates generally used as a phosphate source in catfish feeds.
Magnesium	None	No supplement needed; abundant in feedstuffs.
Sodium, potassium, and chloride	None	No supplement necessary; abundant in feedstuffs.
Sulfur	None	No supplement needed.
Cobalt [3]	0.05 ppm	Cobalt carbonate used to insure adequacy.
Iodine [3]	2.4 ppm	Calcium iodate used to insure adequacy.
Zinc	200 ppm	Phytic acid in feed reduces availability. Zinc oxide generally used.
Selenium	0.1 ppm	Maximum allowable by FDA is 0.1 mg/kg. Sodium selenite used.
Manganese [3]	25 ppm	Phytic acid in feed reduces availability. Manganese oxide used.
Iron [3]	30 ppm	Ferrous sulfate and ferrous carbonate used.
Copper [3]	5 ppm	Copper sulfate used.

[1]Recommendations are for advanced fingerlings to marketable size (1-2 pounds).
[2]Amount in finished feed.
[3]A supplement may not be needed when the diet contains 4% or more animal protein.

in catfish feeds without detrimental effects. Unlike high-protein corn gluten meal, corn gluten feed contains a level of xanthophylls similar to that in corn grain, which does not cause yellow pigmentation in catfish flesh.

Animal and Plant Fats and Oils. Animal and plant fats and oils are highly concentrated sources of energy, as well as sources of essential fatty acids. Animal fats used in catfish feeds include catfish offal oil, beef tallow, poultry fat, and menhaden fish oil. Tallow is not recommended for use in winter feeds because it is a saturated fat. Plant oils can be used, but animal fats are generally preferred because they are generally less expensive. Currently, catfish offal oil and menhaden oil are the two predominate oils used in commercial catfish feeds. There is evidence that levels of menhaden oil of about 2% or higher may reduce disease resistance in catfish. Often, the two are blended in equal parts or in a ratio of 75% catfish oil to 25% menhaden oil. Supplemental fat is generally sprayed on the finished feed pellets at a rate of 1–2%, primarily to reduce fines. Fats and oils have a digestible energy value of around 4,000–4,200 kcal per pound for catfish, depending on the particular fat.

Table 9. Retention of vitamins in extrusion-processed catfish feeds.

Vitamin	Retention (%)
Vitamin A (vitamin A acetate)	65 [1]
Vitamin E (DL-alpha-tocopherol acetate)	100 [1]
Thiamine (thiamin mononitrate)	64 [1], 67 [2]
Riboflavin	100 [2]
Vitamin B-6 (pyridoxine hydrochloride)	67 [1], 70 [2]
Folic acid	91 [1]
Niacin	96 [2]
Pantothenic acid	100 [2]
Ascorbic acid (fat-coated)	57 [3]
Ascorbic acid (ethylcellulose-coated)	43 [1], 48 [3]
Ascorbic acid (L-ascorbyl-2-polyphosphate)	77 [1], 83 [4]

[1]From Producer's Feed Company, Belzoni, Mississippi; assayed by Hoffman-Laroche, Inc., Nutley, New Jersey.
[2]From Li, M.H., J.B. Rushing, and E.H. Robinson, 1996, Stability of B-complex vitamins in extruded catfish feeds, Journal of Applied Aquaculture 6 (2):67-71.
[3]From Robinson, E.H., 1992, Vitamin C studies with catfish: Requirements, biological activity and stability, Technical Bulletin 182, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, Mississippi.
[4]From Robinson, E.H., J.R. Brent, and J.T. Crabtree, 1989, AsPP, an ascorbic acid, resists oxidation in fish feed, Feedstuffs 61(40):64-66.

Premixes

Vitamin and mineral premixes are generally added to catfish feeds. They should be formulated to meet nutrient requirements and manufactured using digestible nutrient sources.

Vitamins. Commercial catfish feeds are supplemented with a vitamin premix that provides vitamins in quantities necessary to meet dietary requirements, including losses due to feed processing. Vitamins commonly added to commercial catfish feeds and the amounts recommended are given in Table 8. Recent data on vitamin stability during feed processing (Table 9) and bioavailabilities of some vitamins from feed ingredients may allow a reduction in the amount of certain vitamins added to catfish vitamin premixes.

Minerals. Generally, if 4–5% or more animal protein is included in catfish feeds, supplemental trace minerals are not necessary. Since most feeds for food-sized catfish growout usually contain low levels of animal protein, a trace mineral premix is commonly added to commercial catfish feeds (Table 8). Trace mineral mixes are commonly manufactured using inorganic sources because of their lower cost. There are reports that in poultry diets, minerals bound to organic compounds — such as proteins, peptides, or amino acids (chelated minerals) — are more available than inorganic minerals. A catfish study conducted at Auburn University showed that zinc methionine was more available than zinc sulfate. In contrast, studies conducted at the DBES showed that zinc methionine was no better than zinc sulfate for improving growth and increasing bone zinc of catfish. Research conducted by USDA researchers at Auburn, Alabama, showed no benefit in using iron methionine over iron sulfate in catfish diets.

Feed Formulation

Catfish feeds have generally been based on a fixed formula with little use of a least-cost approach as is used in other animal industries. In the past, fixed formulas were used because of the lack of sufficient nutritional information. Presently, nutritional data are available to allow the nutritionist to formulate catfish feeds on a least-cost basis. The primary constraint limiting the use of least-cost programs for formulating catfish feeds is that relatively few feedstuffs are available that can be used in catfish feeds. Many feedstuffs are unsuitable for use in catfish feeds because of their poor nutritional content or because of manufacturing constraints. Nutrient levels recommended for practical catfish feeds are given in Table 8.

To use a least-cost computer program to formulate feeds, the following information is needed: (1) cost of feed ingredients; (2) nutrient concentrations in feedstuffs; (3) nutrient requirements; (4) nutrient availability from feedstuffs; and (5) nutritional and nonnutritional restrictions. Several constraints limit the widespread use of least-cost formulation of catfish feeds in addition to the lack of a sufficient number of suitable feedstuffs. These include a lack of knowledge of the nutrient levels that result in maximum profit as opposed to levels that maximize weight gain, a lack of capacity to store large number of different ingredients at the feed mills, and the logistics of obtaining a wide assortment of feedstuffs on a timely basis. However, a limited application of least-cost feed formulation is used to formulate catfish feeds. Cottonseed meal, milo, and meat and bone/blood meal are often used to replace a part of soybean meal, corn, and fish meal, respectively, depending on cost.

Examples of restrictions placed on nutrients and feed ingredients for least-cost formulation of catfish feeds are presented in Table 10. Examples of formulations for commercial catfish feeds used for fry, fingerling, and food fish are given in Table 11.

Table 10. Restrictions for least-cost formulation of a 28%-protein feed for catfish.

Item	Restriction	Amount
Crude protein	Minimum	28.00%
Crude fiber	Maximum	7.00%
Lipid	Maximum	6.00%
Available phosphorus	Minimum	0.30%
Available phosphorus	Maximum	0.40%
Digestible energy	Minimum	2.8 kcal/g
Digestible energy	Maximum	3.0 kcal/g
Available lysine	Minimum	1.43%
Available methionine	Minimum	0.26%
Available methionine + cystine	Minimum	0.65%
Grain or grain by-products	Minimum	25.00%
Cottonseed meal [1]	Maximum	15.00%
Whole fish meal	Minimum	2.00%
Nonfish animal protein	Minimum	2.00%
Xanthophylls	Maximum	11 ppm
Vitamin premix [2]	Include	
Trace mineral premix [2]	Include	

[1]Higher levels may be used if supplemental lysine is used.
[2]Meet dietary allowances for catfish given in Table 8.

Table 11. Examples of ingredient composition (%) of typical fry, fingerling, and food-fish feeds.

Ingredient	Fry feed (50%) [1]	Fingerling feed (35%)	Food-fish feed (32%)	(32%)	(32%)	(28%)	(28%)	(26%)
Soybean meal (48%) [1]	–	38.8	35.0	34.6	48.4	24.4	29.7	32.9
Cottonseed meal (41%)	–	10.0	10.0	12.0	–	10.0	10.0	–
Menhaden meal (61%)	60.2	6.0	4.0	–	–	4.0	–	–
Meat/bone/blood (65%)	15.3	6.0	4.0	8.0	4.0	4.0	4.0	4.0
Corn grain	–	16.1	29.9	30.3	30.2	35.5	34.0	40.6
Wheat middlings	19.0	20.0	15.0	15.0	15.0	20.0	20.0	20.0
Dicalcium phosphate	–	1.0	0.5	0.5	0.75	0.5	0.75	0.75
Catfish vitamin mix [2]	include	include	include	include	include	include	include	include
Catfish mineral mix [2]	include	include	include	include	include	include	include	include
Fat/oil [3]	5.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5

[1]Values in the parentheses represent percentage protein.
[2]Commercial mix that meets or exceeds all requirements for channel catfish.
[3]Sprayed on finished feed pellet to reduce feed dust (“fines”).

Feed Manufacture

Feed manufacturing involves the processing of mixtures of feedstuffs and feed additives into a usable physical form. There are several goals and considerations in feed manufacturing, some of which are nutritional and some of which are nonnutritional. Typically, the primary goal is to increase profits of animal production by maximizing the nutritional value of a feedstuff or a mixture of feedstuffs. Depending on the animal species, this process may range from a simple reduction of particle size to forming feed pellets through steam pelleting or extrusion. Unlike feeds used for terrestrial food animals, catfish feeds must be pelleted, water stable, and generally made to float on the water surface. Thus, most commercial catfish feeds are manufactured by extrusion. If a particular feed additive will not withstand the rigors of extrusion, the feed may be manufactured by steam pelleting into a sinking pellet.

Catfish feed manufacturing involves the reduction of particle size, addition of moisture, heat treatment, and high pressure. Thus, the value of certain feedstuffs or feed additives may be lowered during feed processing. However, the overall process should result in a final product of proper form that meets nutrient specifications. The manufacturing process may also inactivate certain undesirable substances present in feedstuffs, reduce the occurrence of molds and bacteria, and improve palatability and digestibility.

Nutritional Considerations

All animals require protein, vitamins, minerals, lipids, and energy for normal growth and other physiological functions. Because the nutrient contribution from natural food organisms is considered minimal in intensive catfish farming, nutrients and energy are provided primarily by prepared feeds. The primary goal in processing feedstuffs into a feed is to maximize the nutritional value of various feed components to meet nutrient requirements.

Nutrient requirements for catfish have been well defined. In formulating and manufacturing catfish feeds, it is essential that the finished feed meet nutrient requirements and be in a form that is readily consumable and is digestible. Feed processing may have a profound effect on certain nutrients and little effect on others. It may make certain nutrients more available and others less available. However, the feed manufacturing process should produce a feed pellet of good quality with the least amount of detrimental effects on the nutrients present.

Nonnutritional Considerations

Although nutritional considerations are of prime importance, nonnutritional factors often influence the composition of the final product. The logistics of procuring and storing feedstuffs and feed additives are primarily nonnutritional considerations. In general, feed ingredients must be economical, consistently available, easily handled in the manufacturing process, and able to withstand the rigors of the manufacturing process. These characteristics are the primary reason that soybean meal and corn have been the main feedstuffs typically used in catfish feeds. Peanut meal and cottonseed meal are often priced economically and could be used in catfish feeds, but their use is limited not only because of nutritional deficiencies but also because they are not available on a consistent basis during the catfish growing season.

Even if a large number of feedstuffs were available for use in catfish feeds, lack of ingredient storage bins would limit their use. Most catfish feed mills, even high-volume mills, have storage bins for only six to seven feedstuffs. Storage is limited and feedstuffs are used rapidly; thus, they must be replenished almost on a daily basis.

When formulating catfish feeds, the feed manufacturing process must be considered because there is an interrelationship between feed formulation and feed manufacturing. For example, extrusion requires that at least 25% of the feed be composed of grains or grain milling by-products for proper gelatinization and expansion necessary for good pellet stability and floatability. This is generally not a problem, but the type and amount of grain or grain milling by-products that are used may be affected by humidity in the air. Levels of wheat middlings up to 25% generally can be used except in highly humid areas, where the level may be reduced to 10–15% and the amount of corn grain increased to avoid making the feed too sticky and difficult to handle. High-fat feedstuffs, such as rice bran, are generally limited to 5–10% of the feed because high levels of fat make the feed more difficult to pellet or extrude, at least with the equipment commonly used to manufacture catfish feeds in the southeastern United States. Supplemental fat is sprayed on the finished catfish feeds to reduce fines. Highly fibrous feedstuffs must be limited to low levels because high levels of fiber reduce pellet quality. Another consideration during catfish feed manufacture is that the conditions of high temperature, pressure, and moisture encountered during pelleting and extrusion destroy certain nutrients and improve the availability of others. Vitamins are particularly sensitive to destruction; thus, catfish feeds are normally overfortified with vitamins to account for losses during feed manufacture. Energy digestibility of starch appears to be enhanced by the extrusion process.

Manufacturing Processes

Catfish feeds are manufactured in modern feed mills (Figure 1) specifically designed for manufacturing fish feeds. Regardless of whether a feed is floating or sinking, the general scheme of feed manufacture is the same (Figure 2). Whole grains are ground through a hammer mill before batching. The feed ingredients are batched, weighed, mixed, and then reground. After regrinding, mixed feed ingredients are either extruded or steam pelleted and then cooled or dried, fat coated, and stored for loadout. During preparation for loadout, the feed is screened to remove fines and then bagged or loaded into trucks for bulk delivery. Operation of the various phases of feed manufacture is controlled by operators from a control center (Figure 3).

Figure 1. Catfish feed mill located in the Mississippi Delta.

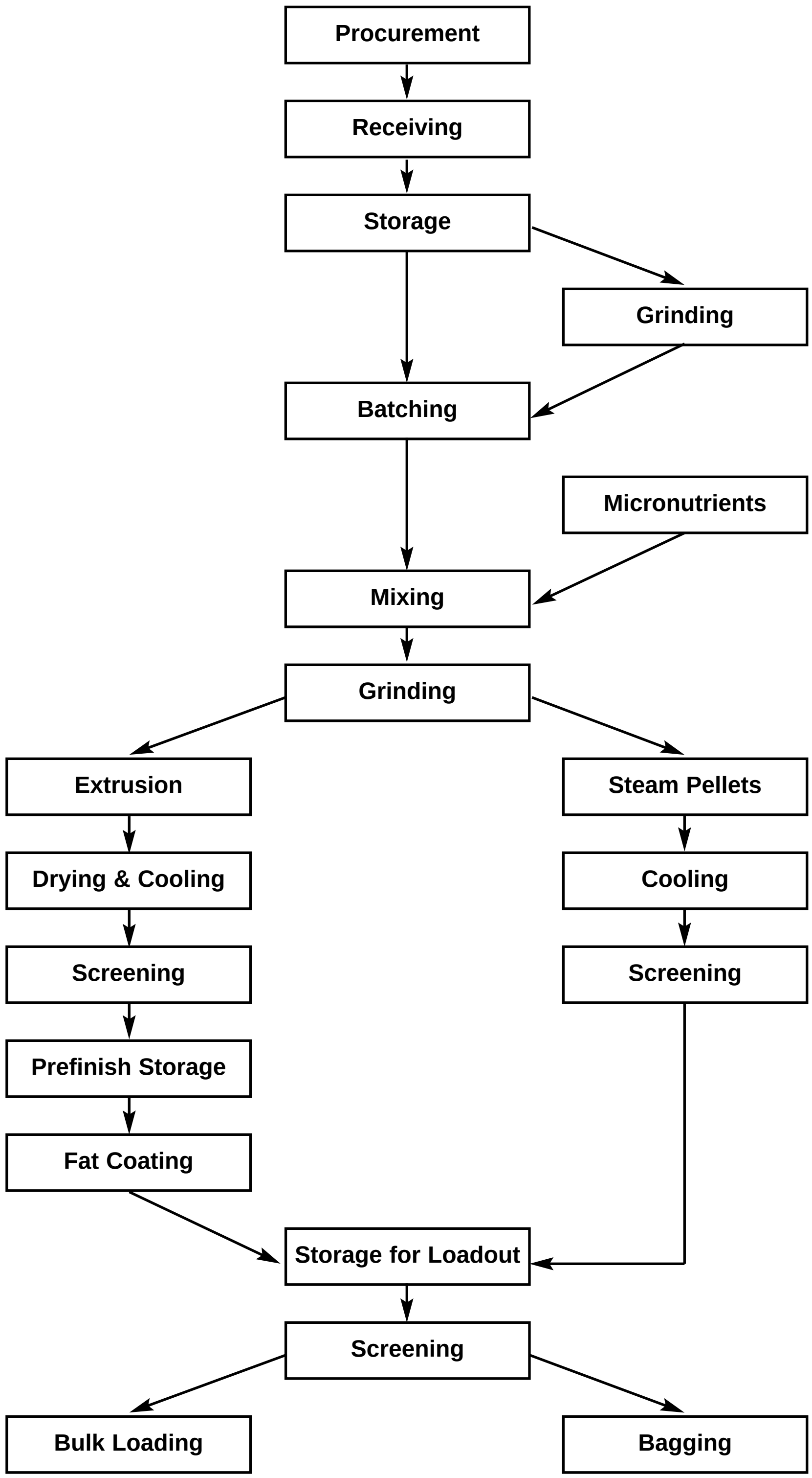

Figure 2. Typical flow scheme for manufacturing catfish feeds.

Figure 3. Control center for catfish feed mill.

Receiving and Storage

Feedstuffs and other ingredients are received at the mill by rail or truck. Rail is generally more economical. Feedstuffs are unloaded from the railcars or trucks and transferred to storage houses or bins. As feedstuffs are needed, they are moved by belt conveyers or screw conveyers to the appropriate section of the feed mill for processing.

Grinding, Batching, and Mixing

Whole grains (corn, wheat, etc.) are ground through a number-7 screen in a hammer mill before batching and mixing. During batching, feed ingredients are conveyed to a hopper above the mixer and weighed before mixing. After batching, the ingredients are dropped into a mixer and mixed for a predetermined time (usually 1–2 minutes). When mixing has been completed, feed mixture is reground through a smaller screen — a number 4 or 6 depending on the type of feed being manufactured — and moved into hoppers above the extruders or the pellet mill.

Steam Pelleting

Steam-pelleted (sinking) feeds are manufactured by using moisture, heat, and pressure to form ground feed ingredients into larger homogenous feed particles. Steam is added to the ground feed ingredients to increase the moisture level to 14–15% and temperature to 160–185ºF. Steam helps to gelatinize starch, which binds the feed particles together. The hot "mash" is then forced through a pellet die in a pellet mill. Die size is dependent on the size of pellet desired. The pellets exit the die at about 14–15% moisture and at a temperature about 10ºF above the temperature of the incoming mash. Pellets coming from the pellet mill are fragile and must be immediately cooled and dried in the pellet cooler.

Steam-pelleted feeds are generally less expensive to manufacture than extruded feeds because less energy is expended in their manufacture. In addition, less destruction of nutrients occurs during steam pelleting as compared with extrusion. A typical steam-pelleted feed is shown in Figure 4.

Figure 4. Examples of various feed types: top left, meal-type feed to feed fry stocked in nursery ponds; top middle, crumbled feed; top right, extruded (floating) fingerling feed; bottom left, extruded (floating) food-fish feed; and bottom right, steam-pelleted (sinking) feed.

Figure 5. Extrusion cooker for manufacturing floating feeds.

Extrusion

Extrusion cooking (Figure 5) is a process that involves the plasticizing and cooking of feed ingredients in the extruder barrel by a combination of pressure, heat, and friction. Fish feed ingredients are a mixture of starchy and proteinaceous materials that are moistened to form a mash. The mash may be preconditioned in a conditioning chamber for 2.5–3 minutes during which moisture is added in the form of steam (water can also be injected) to increase the moisture level of the mash to about 25%. During this period, the mash is cooked as heat and moisture penetrate the feed particles. Preconditioning may improve flavor development and feed digestibility, reduce extruder barrel wear, and allow for increased throughput from the extruder. After preconditioning, the mash enters the extruder, which moves the feed mixture through the extruder barrel that contains a rotating screw. Temperatures in the extruder generally range from 190–300ºF and are generated from the injection of steam into feed mixture and friction of the feed moving through the barrel. The superheated mixture is then forced through a die (about 1/8–1/4 inch in diameter for catfish feeds) located at the end of the extruder barrel. The die restricts product flow, thus causing development of the necessary pressure and shear. The die is also used to shape the product (extrudate) passing through it. As the product passes through the die, a sudden reduction in pressure results in the vaporization of part of the water in the mixture and the feed pellets expand. A typical extruded catfish feed is shown in Figure 4.

Drying and Cooling

Steam-pelleted feeds exit the die at a moisture level of 14–15% and require cooling and drying. The hot, moist pellets are transferred to the pellet cooler, where temperature and moisture content are reduced by evaporative cooling, which is achieved by passing large volumes of ambient-temperature (unheated) air through the pellets. Final temperatures should be equivalent to ambient temperature, and moisture content should be about 8–10%. The moisture level of the pellets leaving the extruder is higher (18–21%) than that of steam-pelleted feed; thus, extruded pellets must be dried with heat. Extruded feeds lose some moisture by flash evaporation and evaporative cooling (about 2%). Extruded feeds should be dried to a moisture content of 8–10%. At this level of moisture, the shelf life of the product is extended. Drying is generally accomplished using a multistage dryer (Figures 6 and 7), which has different temperature zones. For extruded catfish feeds, drying time is around 30 minutes and temperatures range from 275–300ºF.

Figure 6. Multistage dryer-cooler.

Figure 7. Dried floating feeds in multistage dryer-cooler.

Screening, Fat Coating, Storage, and Delivery

After drying, pellets are screened to remove fines, which are reclaimed and used as a feed ingredient. Extruded catfish feeds are normally passed through a fat coater, which applies a thin layer of fat to the pellet surface to help reduce fines. After fat coating, the product is stored in bins awaiting loadout. Just before loadout, feeds are screened again to remove fines. Almost all commercial catfish feeds are delivered to the farm in bulk by truck.

Pellet Grinding or Crumbling

Feeds of a small particle size (flours, meals, or crumbles) are needed for feeding catfish fry and small fingerlings. Flour- or meal-type feeds (Figure 4) are usually prepared using one of two methods: (1) reducing the particle size of a pelleted feed by grinding and screening to the appropriate size; or (2) finely grinding feed ingredients to a particle size of about 1/64 inch or smaller and mixing the ground ingredients. Crumbles (Figure 4) are usually prepared by crushing (crumbling) pelleted or extruded feeds and screening for proper size. If flour- or meal-type feeds are prepared by pelleting and then regrinding to the proper particle size — instead of simply grinding and mixing — water-soluble nutrients are less likely to be lost to the water. Supplemental fat sprayed on the surface of meal or crumbled feeds improves water stability and floatability; it also reduces nutrient losses to the water. Typical meal-type and crumbled feeds are shown in Figure 4.

Quality Assurance

Stringent quality control methods are required to consistently manufacture high-quality feeds that provide essential nutrients in an available form at the proper proportions and levels needed for body maintenance, growth, or reproduction at a reasonable cost. Catfish feed mills have in place continuous and comprehensive quality-assurance programs, whereby various quality-control methods are employed to ensure that all feeds produced are of highest quality. To be effective, a quality-assurance program must be the responsibility of all those involved from top management down. Thus, such a program should encompass all aspects of feed production from feed formulation to the final feed.

Feed Formulation

Catfish feed formulations are based on nutrient requirements established by research conducted at various state and federal agencies. Nutrient requirement data are updated frequently to ensure current data are available for formulating least-cost feeds. Nutrient profiles of feedstuffs are continually updated based on actual assays conducted over a number of years on feedstuffs used and on information supplied by various suppliers of feedstuffs. Feeds are generally formulated to meet nutrient requirements at an economical cost. A safety margin is used to account for variations in the nutrient content of feed ingredients.

Feed Ingredients

The purchasing agent ensures that high-quality ingredients are available on a timely basis at a reasonable cost by having an understanding of feed ingredients and by knowing which suppliers can consistently provide ingredients as needed. Working with the nutritionist and the production manager, the purchasing agent establishes and uses ingredient specifications to ensure that ingredients meet the standards desired. Ingredients are inspected for color, odor, and texture before acceptance. Although subjective, visual and sensory inspection provides useful information on the quality of ingredients before use. An in-house test for moisture or toxins may be performed. Samples are taken for chemical analysis. Analyses are conducted to determine if ingredients meet specifications. In addition, analyses may be conducted to determine presence of toxins, pesticides, or heavy metals. Since chemical tests lag behind ingredient use, a particular ingredient will be used before receiving the analytical results. However, if specifications are not met, a deficiency claim is filed with the supplier. In addition to ensuring quality by inspecting ingredients, ingredient inventories are maintained, which provides information on the amount of an ingredient used over a certain period. This can be used to check and correct errors in the manufacturing process.

Manufacturing

Quality control measures continue during each phase of production to ensure that a feed containing the proper nutrient content with desirable physical characteristics is produced. Ingredients are ground, batched, and mixed, reground, extruded, dried, and fat coated before shipping. All equipment used is selected to produce a quality product. Equipment is continually checked and maintained at proper specifications. Since a uniform mix is essential, mixing is checked periodically by assaying for particular vitamins or other micronutrients.

Finished Feed

The finished product is routinely tested for moisture, protein, fat, and fiber, and it is periodically tested for selected micronutrients to ensure nutritional value. Each batch of feed is checked for physical characteristics, including floatability.

FEEDING

Although considerable research has been conducted on feeding catfish, feeding is far from an exact science. It is a highly subjective process that differs greatly among catfish producers. There does not appear to be one “best” method for feeding catfish, particularly considering that numerous factors (most of which cannot be controlled) affect feeding.

There is considerable variation in feeding practices on commercial catfish farms. Computer programs, which generally determine feeding rate based on a percentage of fish body weight, are available and are used by some catfish producers. Feeding a prescribed amount of feed based on fish biomass in a particular pond works best when the biomass in each pond is known and a accurate estimate of feed conversion can be made. However, most catfish producers do not clean-harvest but rather remove only harvestable-sized fish and replace harvested fish with fingerlings (multiple-batch cropping system). After several harvests and restockings, it is difficult to accurately determine biomass. In fact, many catfish producers judge their inventory by the amount of feed fed. Therefore, catfish are generally fed once daily to what is commonly called “satiation” (i.e., feeding the fish all they will ingest in a reasonable period). However, feeding to satiation is highly subjective and is often difficult to achieve in ponds containing a high standing crop of fish without adversely affecting water quality.

A typical catfish production scheme includes feeding fish in various stages of their life cycle in an aquatic environment that varies widely in temperature and quality. In addition, disease and environmental stressors often influence feeding activity. Thus, to maximize production and profits, catfish should be fed a feed that meets their nutritional requirements using a feeding strategy that is adapted to the specific culture conditions at any given time. That is, under normal conditions catfish should typically be fed daily as much feed as they will consume without adversely affecting water quality. However, depending on water temperature and other water-quality parameters and on the health of the fish, it may be prudent to restrict the daily feed allowance or to feed less frequently. How much to feed and the frequency of feeding are decisions that must be made daily by catfish producers based on each pond of fish. No two ponds of fish are exactly alike, thus feeding behavior in individual ponds may differ greatly or feeding activity in a particular pond may vary greatly from day to day.

The following recommendations given should be considered as guidelines only. No single feed or feeding method is suitable for all circumstances.

Natural Foods

Because of the high level of nutrients introduced by feeding, commercial catfish ponds are fertile and normally contain large numbers of organisms, including phytoplankton, zooplankton, and invertebrates such as insects and crustaceans. Many of these organisms are high in protein and other essential nutrients and may contribute to the diet of pond-raised catfish (Table 12).

The degree to which natural food organisms contribute to the nutrition of intensively grown catfish is still relatively unclear. While some commercially cultured fish that feed low on the food chain (such as tilapia and silver carp) make excellent gains on natural foods, catfish require prepared feeds for maximum yields, except for newly stocked fry, which appear to meet their nutrient requirements from natural food organisms. Although natural food organisms are abundant in most catfish ponds, their contribution to growth of stocker-sized fish generally has been thought to be minimal. For example, studies conducted at Auburn University estimated that only 2.5% of the protein requirement and 0.8% of the energy needed for catfish grown in intensively fed ponds was obtained from natural food.

The major contribution of natural food organisms to the nutrition of commercially cultured catfish may be from nutrients that are required in trace amounts, such as vitamins, minerals, and essential fatty acids. Recent studies with catfish have shown that while vitamin deficiencies could be produced by feeding catfish purified diets devoid of various vitamins in aquaria under controlled laboratory conditions, the same deficiencies could not be produced in catfish raised in ponds fed practical feeds lacking a supplement of a specific vitamin. Thus, the vitamin requirement was met either from vitamins naturally occurring in feedstuffs, natural food organisms, or from a combination of the two. Studies also have been conducted with minerals and essential fatty acids with similar results. These data indicate that catfish benefit from consuming natural food organisms.

Table 12. Nutrient composition (dry matter basis) of zooplankton collected during the summer from commercial catfish ponds in the Mississippi Delta.

Nutrient	Concentration
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
Amino acids (% protein)	
Arginine	7.1
Histidine	3.0
Isoleucine	4.1
Leucine	7.3
Lysine	6.8
Methionine	2.3
Cystine	1.1
Phenylalanine	3.9
Tyrosine	6.1
Threonine	4.5
Tryptophan	0.9
Valine	4.6
Alanine	8.0
Aspartic acid	7.9
Glutamic acid	12.3
Glysine	4.8
Proline	4.3
Serine	4.1
Fatty acids [1] (% fat)	
14:0	1.3
16:0	16.4
16:1	2.9
18:0	7.1
18:1	6.2
18:2 n-6	4.1
18:3 n-3	6.3
20:4 n-6	5.9
20:5 n-3	12.0
22:5 n-6	4.3
22:5 n-3	1.5
22:6 n-3	13.9
Total n-3 HUFA [2]	28.4
Total n-6 HUFA	11.1
n-3/n-6 HUFA ratio	2.6
Vitamins	
D	111.0 IU/lb
E	115.0 ppm
B-1	3.4 ppm
B-2	100.0 ppm
B-6	2.5 ppm
B-12	2.2 ppm
Folic acid	1.2 ppm
Niacin	141.0 ppm
Pantothenic acid	20.0 ppm
Biotin	1.5 ppm
Inositol	1,565.0 ppm
C	164.0 ppm
Minerals	
Phosphorus	0.93 %
Calcium	0.39 %
Sodium	0.15 %
Potassium	0.38 %
Sulfur	0.72 %
Magnesium	0.12 %
Iron	622.0 ppm
Manganese	113.0 ppm
Zinc	76.0 ppm
Copper	16.0 ppm

[1]Fatty acids are typically designated by the use of three numbers: the first indicates the number of carbon atoms; the second, the number of double bonds; and the third, the position of the first double bond.
[2]HUFA = highly unsaturated fatty acids with 20 carbons or longer and four or more double bonds.

Fry

Newly hatched catfish fry, which are only about 1/4 inch in total length, are usually held in indoor troughs and tanks for no more than 10 days before being released into outdoor nursery ponds. Initially, catfish fry use their yolk sac as an energy and nutrient source. Once the yolk sac is absorbed (approximately 3–5 days after hatching), fry begin to seek food and should be fed frequently. In the hatchery, fry should be fed finely ground meal- or flour-type feeds (Table 11) containing 45–50% protein supplied primarily from fish meal. Usually, most producers feed catfish fry in the hatchery with trout starter feeds because of their high quality and ready availability. Hatchery-held fry should be fed at a daily rate equal to about 25% body weight divided into eight to 10 equal feedings. Automatic feed dispensers can also be used to deliver the amount of feed prescribed daily at relatively short time intervals.

It is difficult to effectively feed catfish fry recently stocked into large nursery ponds. The tiny fish spread out over the pond and are relatively weak swimmers, so they are not able to move rapidly to areas where manufactured feeds are offered. The best way to ensure good growth and survival of newly stocked fry is to make sure that plenty of natural food is available in the fry nursery pond when the fish are stocked. Natural foods for channel catfish fry include insects, insect larvae, and zooplankton (microscopic crustaceans). Insects and zooplankton eat plant material in the pond, so to produce them in abundance you must either increase natural plant production within the pond by fertilization or apply the plant material directly to the pond. Regardless of how the pond is managed for increased production of natural foods, it is important to plan ahead, because time is needed for the population of insects and zooplankton to become established in the pond.

The simplest way to prepare the pond for stocking fry is to use a chemical fertilizer to stimulate a bloom of phytoplankton (the microscopic plants that give water the green color). The phytoplankton bloom then serves as food for insects and zooplankton. Start fertilizing the pond about 3 weeks before stocking the fry so that ample time is available for development of a bloom. High-phosphorus liquid fertilizers are the most effective fertilizer materials for developing phytoplankton blooms in catfish ponds. Typical analyses for these fertilizers are 10-34-0 and 13-18-0.

Apply about a half-gallon of liquid fertilizer per acre every other day for 10–14 days or until a noticeable bloom develops. After the bloom develops, continue fertilizing the pond once or twice a week for 3–4 weeks after the fry have been stocked. By that time, the fry (now small fingerlings) should be feeding on manufactured feed and fertilization is no longer necessary.

Fertilizing ponds with chemical fertilizers does not always produce a good bloom. A more dependable way to produce abundant natural food is to apply organic material directly to the pond. The organic material serves as a direct food source for insects and zooplankton, and it slowly decomposes to release plant nutrients that stimulate development of a phytoplankton bloom. Good organic fertilizers include alfalfa pellets, cottonseed meal, or any high-quality hay. Start applying the organic material about 2 weeks before stocking fry. Apply the material twice a week at 100–200 pounds per acre. After stocking the fry, reduce the rate to 25 pounds per acre once or twice a week. Adding liquid chemical fertilizer at a half-gallon per acre once or twice a week in addition to the organic fertilizer will produce even more rapid and dependable results. Stop fertilizing the pond when the fingerlings begin vigorously accepting manufactured feed.

Even though fry presumably meet their nutrient needs from natural food organisms, they should be fed once or twice daily using a finely ground feed at a rate equal to 25–50% of fry biomass. Since the feed serves primarily to fertilize the pond, it is not necessary to feed a high-protein feed as is used in the hatchery. Fines from regular 28%- or 32%-protein feeds for food-fish growout are suitable for catfish fry during this phase. Some catfish producers do not feed the flour-type feeds, opting instead for a pelleted or crumbled feed that is largely uneaten but breaks up in the water and serves to keep the pond fertile. After a few weeks, the fry will have grown into fingerlings of 1–2 inches in length and will come to the pond surface seeking food.

Fingerlings

Initially, small fingerlings (1–2 inches) should be fed once or twice daily to satiation using a crumbled feed or small floating pellets (1/8 inch diameter) containing 35% protein (Table 11), a part of which should be supplied by fish meal, meat and bone/blood meal, or a mixture of the two protein sources. Some catfish producers feed fingerlings the same feed they feed during food-fish growout. Fingerlings consume large feed pellets by nibbling on the feed after it begins to soften and break up in the water. Fingerlings appear to grow well using this feeding strategy, but nutrient losses, especially micronutrients, are likely due to leaching of nutrients because of the extended time the pellet is in contact with the water.

Food-Fish

Catfish grown for food are usually stocked as advanced fingerlings of about 5–6 inches in length (about 40–60 pounds per 1,000 fish). They are generally fed a floating feed of approximately 5/32–3/16 inch in diameter containing 28–32% protein (Table 11). It has generally been recommended to start with a 32%-protein feed in early spring, when temperature is relatively low and fish are feeding with less vigor. As the temperature increases and the fish are feeding vigorously, change to a 28%-protein feed and feed to satiation. Starting with the 32%-protein feed appears to be unnecessary because there is strong evidence that the 28%-protein feed can be used throughout the growout phase without detrimental effects. Because management practices vary greatly throughout the catfish industry, the choice of which feed to use is up to the individual catfish producer.

On large commercial catfish farms, feed is typically blown onto the surface of the water using mechanical feeders that are either mounted on or pulled by vehicles (Figure 8). Feeds should be scattered over a large area to provide equal feeding opportunities for as many fish as possible. It is desirable to feed on all sides of the pond, but this is generally not practical on large farms where several ponds of fish must be fed in a limited period. In addition, prevailing winds dictate that feed must be distributed along the upwind levee to prevent it from washing ashore.

Figure 8. Catfish are being fed from a feeder drawn by a tractor along the pond levee.

Typically, catfish producers feed once a day, 7 days a week. Feeding twice a day appears to improve growth and feed efficiency. However, the logistics of multiple feedings on large catfish farms generally make it impractical. Under certain circumstances, less frequent feedings may be desirable. For example, during certain disease episodes it may be beneficial to feed every other day or every third day.

Feed allowance is affected by several factors, including fish standing crop, fish size, water temperature, and water quality. Water temperature has a profound effect on feeding rate (Table 13). As fish size increases, feed consumption as percentage of body weight decreases and feed conversion efficiency decreases (Table 14). Because catfish are generally cultured using a multiple-batch production system in which several sizes of fish are present in the pond, it is recommended that they be fed to satiation. Offering as much feed as possible (without wasting feed) provides a better opportunity for the smaller, less aggressive fish to receive feed. Satiation feeding appears to be particularly important when catfish are fed less frequently than on a daily basis. Although it is recommended that catfish typically be fed as much feed as they will consume, at high standing crops of fish it may be impossible to satiate the fish and maintain water quality at an acceptable standard. As a rule of thumb, feeding rates should not exceed what can be assimilated by organisms in the pond. This is difficult to judge, but long-term average feed allowance generally should not exceed 100–120 pounds per acre per day. However, exceeding this rate for a few days is okay. Overfeeding should be avoided since wasted feed increases production cost by increasing feed conversion (Table 15). In addition, uneaten feed contributes to deterioration of water quality.

Table 13. Example of feeding rate for catfish grown from advanced fingerlings to marketable size.[1]

Date	Water temperature (°F)		Fish size	Feeding rate
	7 a.m.	4 p.m.	(lb/1,000 fish)	(% body weight)
May 1	68	73	110	2.1
May 15	72	79	136	3.4
June 1	70	77	180	2.9
June 15	81	86	244	3.2
July 1	81	88	316	2.7
July 15	82	88	388	2.4
August 1	82	90	513	1.8
August 15	81	86	628	2.0
September 1	77	86	739	1.5
September 15	77	86	841	1.3
October 1	68	72	1,019	1.1

[1]In this example, catfish were grown from advanced fingerlings to marketable size while being fed once daily to satiation from May to October in ponds stocked at rate of 10,000 fish per acre in a single-batch system in the Mississippi Delta.

Table 14. Average feed consumption and feed conversion ratio for different sizes of catfish grown in 1-acre earthen ponds at Thad Cochran National Warmwater Aquaculture Center.

Initial fish weight (lb/fish)	Final fish weight (lb/fish)	Feed consumption (lb/fish)	Feed conversion ratio [1] (feed/gain)
0.06	0.45	0.72	1.74
0.06	0.55	0.88	1.77
0.35	1.23	1.57	2.04
0.86	2.61	3.42	2.53
2.50	5.00	6.10	2.68 [2]

[1]Feed conversion ratio is corrected for mortalities.
[2]A study conducted at the Delta Western Research Center in Indianola, Mississippi, in earthen ponds indicated that catfish grown from about 2.5-3 pounds to 5-6 pounds had a feed conversion ratio of 3.5-4.

Table 15. Feed cost in cents per pound of catfish produced at different feed conversion ratios and feed prices.

Feed conversion ratio (feed/gain)	Feed costs at various feed prices [1]					
	$200/ton	$225/ton	$250/ton	$275/ton	$300/ton	$325/ton
1.3	13	15	16	18	20	21
1.4	14	16	18	19	21	23
1.5	15	17	19	21	23	24
1.6	16	18	20	22	24	26
1.7	17	19	21	23	26	28
1.8	18	20	23	25	27	29
1.9	19	21	24	26	29	31
2.0	20	23	25	28	30	33
2.1	21	24	26	29	32	34
2.2	22	25	28	30	33	36
2.3	23	26	29	32	35	37
2.4	24	27	30	33	36	39
2.5	25	28	31	34	38	41
2.6	26	29	33	36	39	42
2.7	27	30	34	37	41	44
2.8	28	32	35	39	42	46
2.9	29	33	36	40	44	47
3.0	30	34	38	41	45	49
3.5	35	39	44	48	53	57
4.0	40	45	50	55	60	65

[1]For example, at a feed price of $200 per ton and a feed conversion ratio of 1.3, feed cost would be 13 cents per pound of catfish produced.

The best time of day to feed is still debated, but the point is more or less academic. On large catfish farms, the time fish are fed is largely dictated by the logistics required to feed large numbers of ponds in a limited time. Consequently, many catfish producers start feeding early in the morning as soon as dissolved oxygen levels begin to increase. Some catfish producers and scientists argue that it is best to begin feeding midmorning or early afternoon. A study conducted in ponds at the NWAC showed no significant differences in weight gain, feed consumption, feed conversion, and survival among catfish fed to satiation at 8:30 a.m., 4 p.m., and 8 p.m. There were also no differences in emergency aeration time among treatments. However, feeding late afternoon or at night in large commercial catfish ponds is not recommended because adequately aerating a commercial catfish pond is more difficult than for a small experimental pond. Peak oxygen demand generally occurs about 6 hours after feeding. If dissolved oxygen levels are particularly low at this time and aeration is insufficient, fish may be stressed or die. Generally, it appears most practical to begin feeding in the morning as the dissolved oxygen begins to increase.

Brood Fish

Catfish brood stock is usually fed the same feed used for food-fish growout. Some catfish producers prefer using sinking feeds because brood fish are often hesitant to feed at the surface. However, because brooders generally feed slowly, sinking pellets may disintegrate before they can be consumed. It is recommended that catfish brooders be fed a typical 28%- or 32%-protein feed once daily. The feeding rate should be about 0.5–1% fish body weight.

Water temperature dramatically influences the feeding activity of catfish. At temperatures below 70ºF, feeding activity can be inconsistent and feed intake is greatly diminished when compared with summertime feeding activity. However, a winter feeding program appears to be beneficial to prevent weight loss and maintain fish health. Research has shown that significant increases in weight gain can be obtained in fish that were fed during the winter as compared with fish that were not fed during these months. This appears to be particularly true with fingerlings.

The health aspect of winter feeding is less well defined, but logically one would expect fish fed during the winter to be in better condition and perhaps more resistant to disease-causing organisms than fish that were not fed. However, results from studies conducted at Auburn University indicate that food-sized catfish not fed during the winter are more resistant to *E. ictaluri*, but fingerling catfish not fed during the winter are less resistant to *E. ictaluri*. A recent study conducted at the NWAC seems to dispute this observation. Effects on immune responses caused by withholding feed from fish were found to be immediate; that is, withholding feed from fish immediately after bacterial exposure increases chances of survival over fish that are continuously fed during the exposure to *E. ictaluri*. Withholding feed from fish before the development of infection has no significant effect on survival of fish after the *E. ictaluri* exposure.

Often, fish are not fed in the winter because inclement weather may prevent access to pond levees. However, some catfish producers simply do not see any benefit to winter feeding. It has been shown that weight gain of catfish not fed during the coldest winter months catches up with that of fish fed during the winter when satiate feeding is resumed in the spring and summer. However, under a multibatch cropping system with various sizes of fish present, this may not be the case because the larger, more aggressive fish typically consume a disproportionate amount of feed. Thus, smaller fish may be unable to consume enough feed to overcome weight loss experienced during the winter. If fish are to be marketed during the winter, it seems prudent to follow a winter feeding program, particularly during a mild winter.

Even though some catfish producers choose not to feed for various reasons, considering potential weight gains and health benefits, we feel that it is prudent to follow a winter feeding program on commercial catfish farms. Several schedules for winter feeding of fingerlings, food fish, and brood fish have been suggested. Generally, all schedules are such that water temperature dictates feeding frequency. A typical winter feeding schedule is shown in Table 16. Since most production ponds contain mixed sizes of fish at any given time, the feeding schedule chosen should be based, in addition to water temperature, on the number of small fish in the pond that require higher feeding rates and more frequent feedings.

The type of feed that should be fed during the winter has not been precisely defined. A typical growout floating feed containing 28% or 32% protein is sufficient. A 25%-protein, slow-sinking feed (Table 17) is also available and is preferred by some producers. Either of these feeds will provide sufficient nutrition for overwintering catfish.

While it is important throughout the year to ensure that brood fish receive adequate nutrition, it is especially important during the winter. It is at this time of the year that eggs, which were produced by females the previous summer after spawning, are developing yolks and maturing. This process requires that brood fish receive adequate nutrition on a regular basis. Feeding rates should not be restricted too much since the more

Table 16. Winter feeding schedule for fingerling, food, and brood catfish.

Temperature	Fingerling		Food fish		Brood fish	
(ºF)	% BW [1]	Frequency	% BW	Frequency	% BW	Frequency
< 50		Do not feed		Do not feed		Do not feed
50-60	0.5–1.0	1–2 times per week	0.25–0.5	Once a week	0.25–0.5	Once a week
60-70	1.0–2.5	Daily or every other day	0.5–1.0	Every other day	0.5–1.0	2–3 times per week

[1]BW = Body weight.

aggressive male brood fish may outcompete females for feed, which can restrict egg maturation. The most common brood-fish ration used in the winter is the same feed used to feed food fish, either a 28%- or 32%-protein floating pellet. If brood fish appear to be reluctant to feed at the surface, the 25% slow-sink feed can be used. Some catfish producers also stock forage fish (e.g., fathead minnows) into ponds to ensure that adequate food is available during the winter.

Table 17. Typical winter feed for catfish (25% protein, slow sinking).

Ingredient	Pct. of feed
Soybean meal (48%) [1]	18.3
Cottonseed meal (41%)	10.0
Menhaden meal (61%)	4.0
Meat/bone/blood (65%)	4.0
Corn grain	35.1
Wheat middlings	25.0
Dicalcium phosphate	1.0
Catfish vitamin mix [2]	include
Catfish mineral mix [2]	include
Fat/oil [3]	2.5

[1]Values in parentheses represent percentage protein.
[2]Commercial mix that meets or exceeds all requirements for channel catfish.
[3]Sprayed on after extrusion to reduce feed dust "fines."

Feeding Diseased Fish

Feeding diseased fish may be difficult because sick fish feed poorly, if at all. However, offering medication through the feed is generally the only method available to treat bacterial infections. There is considerable debate over the efficacy of medicated feeds (feeds containing antibiotics) and the best method to treat diseased fish. Some catfish producers do not feed during outbreaks of certain diseases, while others limit feed to every other day. Not feeding during ESC outbreaks appears to be as effective as feeding medicated feeds for reducing fish losses.

Medicated Feeds

Antibiotics can be administered to large populations of fish through the feed. Medicated feeds have been used to treat diseased fish for a number of years in other aquaculture industries (i.e., salmon and trout) and have been accepted as the only viable alternative to treat systemic bacterial infections of catfish. Two antibiotics, Romet® (sulfadimethoxine-ormetoprim) and Terramycin® (oxytetracycline), are registered by FDA to treat bacterial infections of catfish through their incorporation into feeds.

Romet is registered for control of enteric septicemia of catfish (ESC) and has been shown effective in treating motile aeromonad septicemia caused by *Aeromonas hydrophila* and systemic columnaris infections. Romet-medicated feed (Table 18) is fed at a feeding rate (dependent on the formulation of Romet used) sufficient to deliver 2.3 grams of antibiotic per 100 pounds of fish per day. Romet was originally formulated to contain 66.6 pounds of Romet-30® premix per ton of finished feed and delivered the required dosage of antibiotic when fed at a rate of 0.5% of fish body weight daily. However, because of palatability problems, the amount added was reduced to 33.3 pounds per ton of feed, and the feeding rate was increased to 1% fish body weight daily.

Data from a recent study conducted at the NWAC indicated that the effectiveness of treating ESC with Romet could be increased by feeding a reduced concentration of antibiotic formulation at a greater rate adjusted to deliver the required legal level of antibiotic. The reason for the increased effectiveness of this feeding strategy could have been be due to the increased availability of medicated feed to larger numbers of sick fish. Thus, catfish feed mills in the Mississippi Delta currently manufacture Romet-medicated feed using 11.1 pounds of Romet-30 per ton of feed. This feed is either fed to satiation or fed at a rate of 3% body weight daily. Romet is heat-stable, so it can be used in a floating feed. Research at the NWAC indicated that the level of fish meal should be increased to 16% to improve the palatability of feeds containing Romet.

Romet is registered by the FDA to be fed at the prescribed rate for 5 consecutive days. If the majority of fish in the pond affected by the disease are fingerlings, feeding smaller feed size (crumbles or 1/8-inch diameter pellets) is usually suggested. This recommendation is based on results obtained in the aforementioned study, which showed that ESC-infected fingerlings fed medicated feed in smaller pellets had better survival than those fed regular-sized medicated feed. If mortality does not decrease after treatment, additional sick fish should be diagnosed. An additional 5-day period of medicated feed may be prescribed. A 3-day, mandatory withdrawal period is required before fish can be slaughtered.

Terramycin is a broad-spectrum antibiotic registered by the FDA to treat *Aeromonas* infections. Terramycin has also been shown effective in treating other aeromonad infections, ESC, and systemic columnaris infections. The most common feed formulation currently used contains 50 pounds of Terramycin TM-100® premix per ton of finished feed. The resulting medicated feed contains 2.5 grams of antibiotic per pound of feed. When fed at 1% of body weight per day, it delivers 2.5 grams of antibiotic per 100 pounds of fish per day.

Terramycin-medicated feeds usually have been manufactured as sinking pellets because the antibiotic is heat-labile and does not withstand the high temperatures required to make floating pellets. However, a new "cold" extrusion process has been developed to make floating Terramycin feeds, which allow the feeder to observe the fish feed during a bacterial disease episode. Floating Terramycin feeds are commercially available and should replace sinking Terramycin feeds because of the advantage of using floating feeds.

Based on field observations, Terramycin-medicated feed is primarily recommended to treat systemic columnaris infections or ESC infections caused by strains of *E. ictaluri* that are resistant to Romet. Terramycin is registered for feeding on 7–10 consecutive days, and a 21-day withdrawal period is required before fish can be slaughtered.

Considerations

Several important considerations should be taken into account when treating fish with medicated feed. An accurate diagnosis of the specific disease(s) affecting the fish population must be obtained before effective treatment can be expected. In many cases, fish are infected with multiple disease agents. For example, fish with a systemic ESC infection may also have a concurrent systemic or external columnaris infection coupled with a parasitic infection. In these situations, the choice of treatment should be made only after careful consideration of the results of an accurate diagnosis.

Producers must also consider bacterial resistance. Some strains of disease-causing bacteria in catfish are resistant to currently available antibiotics; in other words, these bacteria will not be killed by application of the antibiotic. To avoid problems associated with bacterial resistance, a sensitivity test of the bacteria in question should always be obtained. In a sensitivity test, the infective bacteria are cultured under laboratory conditions and exposed to available antibiotics. If the bacteria are not affected by the antibiotic, they are resistant and an alternative treatment strategy is recommended. Sensitivity tests are routinely conducted by fish disease diagnostic laboratories.

Bacterial resistance to antibiotics may result from indiscriminately feeding medicated feed or from using feeding schedules not prescribed by the FDA. Once a bacterial strain becomes resistant to an antibiotic, it may be impossible to treat future disease outbreaks due to the lack of effective legal antibiotics.

When using medicated feed, every effort should be made to ensure that fish consume the feed and receive the proper dose of antibiotic. Several practices can help ensure that fish consume the feed. Fish should be submitted for diagnosis as soon as any potential problems are observed. If disease outbreaks are allowed to progress for a long period, fish may be too weak to feed and treatment with medicated feed will prove useless. Fish should be fed when dissolved oxygen concentrations are relatively high. Feeding fish more than once a day and feeding over a large portion of the pond rather than in one area may also help increase consumption of medicated feed.

When treating fish with medicated feed, losses of fish may not immediately subside. Even if detected

Table 18. Typical Romet®-medicated feed (32% protein[1]) for catfish.

Ingredient	Pct. of feed
Soybean meal (48%) [2]	26.8
Cottonseed meal (41%)	10.0
Menhaden meal (61%)	16.0
Corn grain	23.0
Wheat middlings	20.0
Dicalcium phosphate	1.0
Catfish vitamin mix [3]	include
Catfish mineral mix [3]	include
Fat/oil [4]	1.5
Romet	1.65

[1]Protein levels not critical. Could be lowered, but fish meal needs to remain at 16%.
[2]Values in parentheses represent percentage protein.
[3]Commercial mix that meets or exceeds all requirements for channel catfish.
[4]Sprayed on after extrusion to reduce feed dust "fines."

early, bacterial diseases may affect a portion of the fish in a pond to an extent that they will not consume feed. These fish normally will continue to die during and after the treatment period, but the remaining fish in the pond that consume medicated feed have a good chance for recovery.

Effect of Feeds on Processing Yield of Catfish

Processing yield is an important economic measure for the success of the catfish processing industry. Several factors may influence processing yield, including fish size and age, sex and maturity, feeding rate, diet composition, and the adjustment and maintenance of processing equipment. Generally, as dietary protein decreases and DE/P ratio increases, catfish tend to deposit more fat in the muscle mass and body cavity, which may result in reduced carcass and fillet yield. Recent pond studies were conducted at the NWAC using processing equipment similar to that used in the catfish processing industry. Resulting data showed that catfish fed diets containing 28% and 32% protein with DE/P ratios of 10 and 9 kcal/gram, respectively, had a similar carcass and fillet yield. However, diets containing 26% or less protein sometimes result in a lower carcass and fillet yield. Data also indicated that the amount of animal protein in the diet did not affect processing yield of catfish.

Effect of Feeds on Sensory Quality of Processed Catfish

Flavor

Commercial feeds composed of oilseed meals, grains, and animal products generally have little influence on flavor quality of farm-raised catfish. A study was conducted at the USDA Agricultural Research Service Southern Regional Research Center in New Orleans, Louisiana, to evaluate the effects of feed ingredients on flavor quality of farm-raised catfish. Commonly used feed ingredients were substituted individually into semipurified experimental diets at levels commonly used in commercial feeds. The diets were fed to catfish under laboratory conditions for 2 months, and fish were evaluated for flavor quality by a trained panel using quantitative sensory techniques. Results showed no significant differences in flavor among fish fed different experimental diets.

High levels of dietary marine fish oil may give catfish an undesirable “fishy” flavor, but catfish fed feeds containing 2% menhaden oil (this level is rarely exceeded in feeds for food-sized catfish) have no distinct fishy flavor. Off-flavor problems of farm-raised catfish are predominantly influenced by phytoplankton, some of which can excrete certain metabolites that are absorbed by fish. Phytoplankton growth is related to feed input, so increased feeding rates may affect fish flavor indirectly by influencing phytoplankton growth.

Appearance

Consumer acceptance of farm-raised fish depends mainly on the color of the flesh. The preferred color of catfish flesh is white. At high dietary levels, the yellow pigments (xanthophylls) have been shown to concentrate in catfish, giving the flesh an undesirable yellowish coloration. Corn gluten meal is eliminated as a feed ingredient in catfish feeds because of its high concentration of xanthophylls. Corn and corn screenings contain the pigment, but it is present at concentrations that are not problematic. Otherwise, feeds appear to have little effect on appearance of catfish flesh.

Fattiness

The amount of body fat found in catfish is influenced by several factors, including feeding rate, fish size and age, and dietary protein level and energy/protein ratio. Regardless of fish age and feeding rate, as dietary protein level decreases and the energy/protein ratio increases, body fat increases. Regardless of dietary protein and energy levels, fish fed to satiation generally contain more fat than fish fed at restricted levels. Presently, body fat of catfish is higher than it was 20 or 30 years ago because catfish are fed more liberally today.

There is evidence that feeding synthetic compounds, such as Ractopamine and carnitine, may reduce body fat in catfish. Ractopamine is a “repartitioning agent” that can repartition fat to synthesize protein, while carnitine is a natural compound that acts as a catalyst for fat metabolism. However, these compounds have not been approved for use by FDA.

A major concern about fattiness of catfish is that increasing fat in edible tissue may reduce the shelf life of frozen fish. However, a cooperative study involving several universities has shown that body fat content has little effect on storage quality of frozen catfish products.

Compensatory Growth

After a period of feed deprivation or restriction, animals have the potential to compensate or "catch up," resulting in increased growth rate after full feeding is resumed. This phenomenon is called compensatory growth. It is well documented that compensatory growth occurs in mammals, and it appears to occur in fish. A study conducted at Auburn University indicated that catfish have the ability to make up weight gain after a 3-week, restricted-feeding regimen, in which fish were fed every third day during the summer. Another study at Auburn University showed that catfish not fed during December, January, and February could make up for the weight loss if the fish were fed as much as they would consume the following spring and summer. These studies clearly indicate that catfish exhibit compensatory growth. This finding is of practical importance because fish are often fed infrequently or not fed during the winter due to factors such as inclement weather, holidays, and hunting season. However, it should be noted that these studies were conducted at relatively low standing crops with fish of a single size class. In the typical multibatch cropping system used to raise catfish, the results may differ. Also, feeding to satiation is essential for compensatory growth, but at high standing crops, the amount of feed necessary for satiation may exceed the capacity of the pond to "assimilate" the input and avoid poor water quality.

Although compensatory growth does occur, it should not be taken as a substitute for good feed management. That is, compensatory growth may not always allow catfish to make up for weight lost during periods when feeding is severely restricted or withheld. Therefore, we recommend that catfish be fed daily during the growing season when culture conditions allow for it.

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