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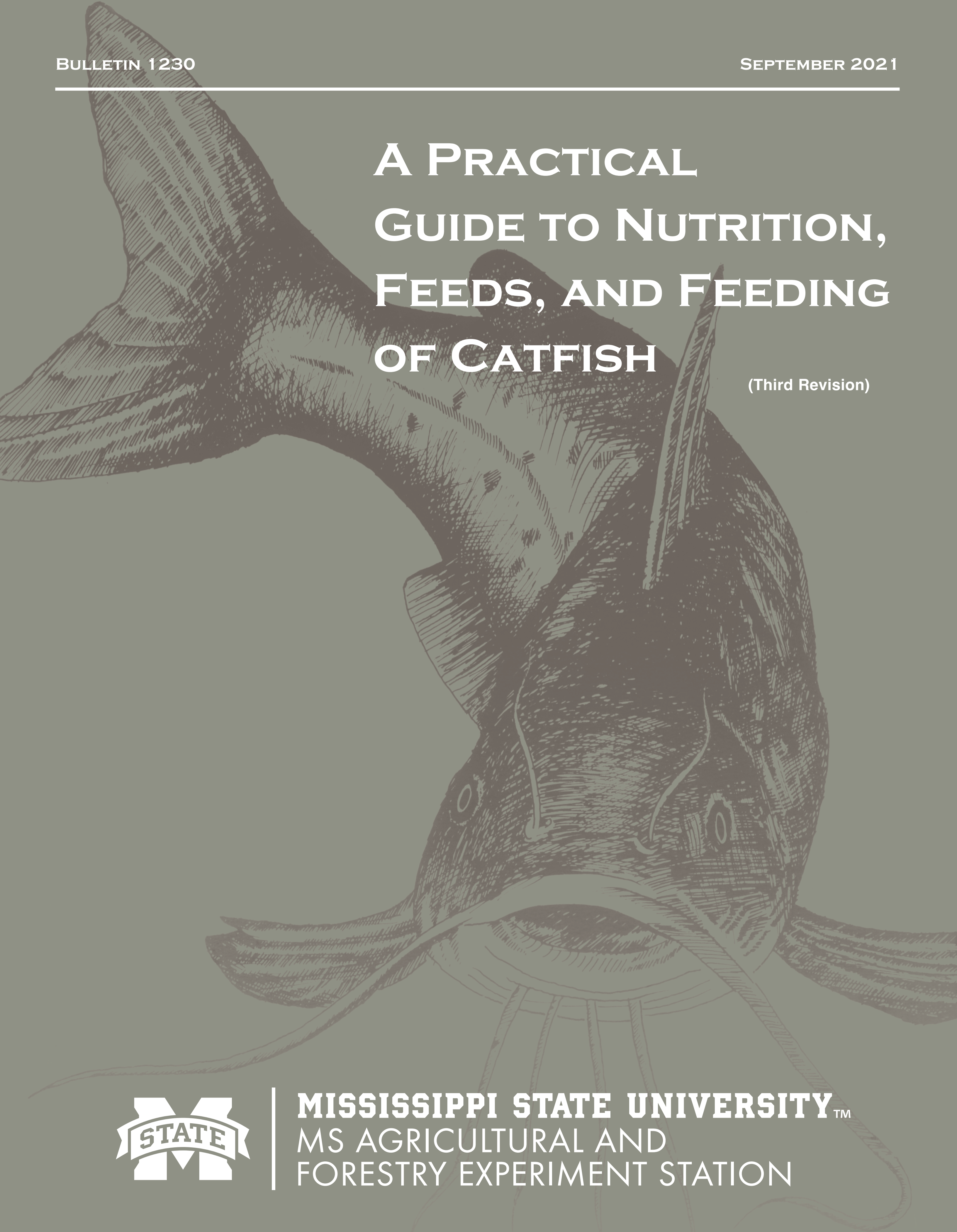

A Practical Guide to Nutrition, Feeds, and Feeding of Catfish

(Third Revision)

Mississippi State University™
MS Agricultural and
Forestry Experiment Station

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

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Preface

It has been nearly two decades since the publication of the last revision of this bulletin, during which a considerable amount of nutritional data has been compiled. Catfish husbandry practices have undergone changes as well. As a result of these developments, feed composition and feeding practices have been modified. This new information is included in this revision, though much of the bulletin remains unchanged. The recommendations made herein apply to current industry practices but yet provide a point of reference that can be used to respond to future advances. Catfish refers to channel catfish, unless otherwise noted. Since this bulletin is intended to be a practical guide, technical details are kept to a minimum and references have not been used, except for those in footnotes.

The authors appreciate the support of the Mississippi Agricultural and Forestry Experiment Station, Delta Research and Extension Center, and Thad Cochran National Warmwater Aquaculture Center (NWAC) for funding for this bulletin. We thank all current and former personnel at the Catfish Nutrition Laboratory and NWAC pond facility who assisted the data collection. Special thanks go to Jimmy Avery, Ganesh Kumar, and Charles Mischke for critical review of the manuscript.

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Introduction

Catfish nutrition research in the United States began in the 1950s and is still ongoing today. During the past seven decades, countless studies have been conducted on catfish nutrition, feeds, and feeding practices. Thus, catfish nutrient requirements and feeding behavior are well defined. This has led to the development of nutritious, cost-effective, sustainable, and environmentally friendly feeds, as well as to feeding strategies for all phases of catfish production. These developments have been instrumental to the success of the catfish industry. This bulletin summarizes current knowledge of nutrition, feeds, feeding practices, and related topics for pond-raised catfish.

Nutrient Digestion and Absorption

Digestion and absorption occur primarily within the stomach and intestine, but the pancreas, liver, and gallbladder are also part of the digestive process. Digestion involves the mechanical reduction of food particle size and solubilization of these particles by digestive enzymes, stomach acid, and emulsification. Nutrients released during digestion are then absorbed by intestinal epithelial cells and transported to various tissues via the lymph or blood. The stomach is acidic (pH 2–4), which is particularly important in digesting protein and solubilizing minerals. For example, proteins are partially hydrolyzed (broken down) by stomach acid and gastric protease enzyme pepsin into smaller compounds. Minerals are solubilized under the acidic conditions in the stomach, which aids in their absorption. As food is released into the intestine, which in contrast to the stomach is basic (pH 7–9), proteins continue to be degraded by pancreatic and intestinal protease enzymes into absorbable small peptides and amino acids. Lipid (fats and oils) digestion occurs primarily in the intestine. Triglycerides, the primary components of lipids, are emulsified into small fat droplets by bile salts (produced by the liver and released via the gall bladder), and then broken down by pancreatic lipase enzymes into free fatty acids and monoglycerides. These are further emulsified to form even smaller fat droplets (micelles) that are taken up by intestinal epithelial cells and formed into new triglycerides. These triglycerides aggregate with cholesterol, phospholipids, and proteins to form lipoprotein particles (chylomicrons) that enter the lymph and then the blood. Carbohydrates (starch) are also digested in and absorbed from the intestine. Starch is hydrolyzed by pancreatic and intestinal amylase and maltase enzymes to glucose absorbed via intestinal epithelial cells. Water-soluble vitamins are absorbed by diffusion from the intestine, and fat-soluble vitamins are absorbed along with triglycerides. Almost all mineral absorption occurs in the intestine, but some minerals (such as calcium) can be taken in through the gills by diffusion from the water. Intestinal absorption of minerals is controlled in part by hormones and tissue mineral concentration of stored minerals. Vitamin D is required for absorption of calcium from the intestine.

Digestibility coefficients or availability coefficients (a term used for amino acids and minerals) represent the percentage of a nutrient digested or available for absorption. These values have been determined for various nutrients and energy for feedstuffs commonly used in catfish feeds (Tables 1–3). Protein digestibility coefficients generally reflect amino acid availability, but there is one notable exception. The protein digestibility of cottonseed meal for catfish is 81–83%, but because lysine is chemically bound to a compound found in cottonseed meal, its availability is only 66%. Several factors may affect digestibility, including feeding rate, feeding frequency, and environmental temperature. However, digestibility was not affected in catfish fed at rates of about 70–100% of satiation. Digestion was also unchanged in catfish fed once daily or every other day to satiation, or at water temperatures of 75–86 °F.

Table 1. Apparent digestibility (%) of protein, fat, starch, and energy for various feedstuffs determined for catfish.[1]

Feedstuffs	Protein	Fat	Starch	Energy
Soybean meal, dehulled, solvent (47%[2])	84–97	97	—	72–79
Cottonseed meal, solvent (41%)	81–83	81	—	56–80
Peanut meal, solvent (47%)	74–86	76	—	76
Canola meal, solvent (38%)	77–91	92	—	52–72
Distillers dried grains with solubles, corn (27%)	87	94	—	59
Fish meal, menhaden (62%)	78–90	97–100	—	85–97
Porcine meat and bone meal (52%)	80	99	—	84
Poultry by-product meal (57%)	65–91	100	—	82–91
Corn grain, cooked	66–97	96	78	59
Corn germ meal	84	92	—	57
Corn gluten feed	75–88	93	—	42–52
Wheat grain	84–92	96	59	60–63
Wheat bran	82	—	—	56
Fish oil, menhaden	—	97	—	–

[1] Source: Cruz, E.M. 1975. Determination of nutrient digestibility in various classes of natural and purified feed materials for channel catfish, PhD dissertation, Auburn University, AL.
Brown, P.B., R.J. Strange, and K.R. Robbins. 1985. Protein digestibility coefficients for yearling channel catfish fed high protein feedstuffs. The Progressive Fish-Culturist 47:94–97.
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Kitagima, R.E., and D.M. Fracalossi. 2011. Digestibility of alternative protein-rich feedstuffs for channel catfish, *Ictalurus punctatus*. Journal of the World Aquaculture Society 42:306–312.
Li, M.H., D.F. Oberle, and P.M. Lucas. 2013. Apparent digestibility of alternative plant-protein feedstuffs for channel catfish, *Ictalurus punctatus*. Aquaculture Research 44:282–288.
[2] Values in parenthesis are crude protein. Source: Fowler, J. 2019. Feedstuffs ingredient analysis table, 2019-2020 edition (https://www.feedstuffs.com), except porcine meat and bone meal which was analyzed in-house.

Table 2. Apparent essential amino acid availability (%) of various feedstuffs determined for catfish.[1]

Feedstuffs	Arg[2]	His	Ile	Leu	Lys	Met	Cys	Phe	Tyr	Thr	Trp	Val
Soybean meal, dehulled, solvent (47%[3])	95–96	84–94	78–93	81–91	91–94	80–89	91	81–92	79–93	78–90	97	76–92
Cottonseed meal, solvent (41%)	90	77	69	74	66	73	—	81	69	72	—	73
Peanut meal, solvent (47%)	97	83	90	92	86	85	—	93	91	87	—	90
Canola meal, solvent (38%)	84–86	85–94	77–92	79–87	79–83	83–93	80–93	78–85	77–86	74–77	96	80–90
Distillers dried grains with solubles, corn (27%)	84	85	83	88	72	85	82	83	84	72	89	94
Fish meal, menhaden (62%)	89–94	79–93	85–91	86–95	83–95	81–92	83	84–93	85–94	83–94	99	84–92
Porcine meat and bone meal (52%)	84	85	77	82	85	83	—	84	86	79	95	78
Poultry by-product meal (57%)	89	93	81	90	90	98	98	90	98	85	—	86
Corn grain	74	78	57	82	69	62	—	73	69	54	—	65
Corn germ meal	86	83	79	83	78	80	78	81	78	74	86	80
Corn gluten feed	71–80	78–88	74–93	79–87	67–76	69–92	73–92	76–82	75–93	75–78	90	77–89
Wheat middlings	92	87	82	85	86	77	—	87	83	79	—	85

[1] Sources: Wilson, R.P., and E.H. Robinson. 1982. Protein and amino acid nutrition for channel catfish, MAFES Bulletin 25, Mississippi State, MS.
Kitagima, R.E., and D.M. Fracalossi. 2011. Digestibility of alternative protein-rich feedstuffs for channel catfish, *Ictalurus punctatus*. Journal of the World Aquaculture Society 42:306–312.
Li, M.H., D.F. Oberle, and P.M. Lucas. 2013. Apparent digestibility of alternative plant-protein feedstuffs for channel catfish, *Ictalurus punctatus*. Aquaculture Research 44:282–288.
[2] Arg: arginine; His: histidine; Ile: isoleucine; Leu: leucine; Lys: lysine; Met: methionine; Cys: cysteine; Phe: phenylalanine; Tyr: tyrosine; Thr: threonine; Trp: tryptophan; Val: valine.
[3] See footnote 2 in Table 1.

Table 3. Apparent phosphorus availability (%) of various feedstuffs determined for catfish.[1]

Feedstuffs	Phosphorus availability (%)
Soybean meal, dehulled, solvent (47%[2])	29–36
Cottonseed meal, solvent (41%)	22
Distillers dried grains with solubles, corn (27%)	77
Fish meal, menhaden (62%)	39–46
Meat and bone meal, unspecified (50%)	53
Corn grain	25–34
Corn gluten feed	75
Wheat middlings	20–28
Dicalcium phosphate	65–75
Monocalcium phosphate	81
Monosodium phosphate	89–90

[1] Sources: Lovell, R.T. 1978. Dietary phosphorus requirement of channel catfish (*Ictalurus punctatus*). Transactions of the American Fisheries Society 107:617–621.
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.
Eya, J. C. and R.T. Lovell. 1997. Net absorption of dietary phosphorus from various inorganic sources and effect of fungal phytase on net absorption of plant phosphorus by channel catfish, *Ictalurus punctatus*. Journal of the World Aquaculture Society 28:386–391.
Buyukates, Y, S.D. Rawles, and D.M. Gatlin, III. 2000. Phosphorus fractions of various feedstuffs and apparent phosphorus availability to channel catfish. North American Journal of Aquaculture 62:184–188.
Li, M.H., E.H. Robinson, and P.M. Lucas. 2015. Apparent phosphorus availabilities of selected traditional and alternative feedstuffs for channel catfish. North American Journal of Aquaculture 77:136–140.
[2] See footnote 2 in Table 1.

Nutrient and Energy Requirements

Some 40 nutrients have been identified as necessary for the normal growth and metabolic functions of catfish. Nutrient and energy requirements for catfish have generally been based on weight gain, feed efficiency, and body composition of small fish raised in the laboratory. However, over the years, substantial data have been collected on the nutrient requirements of pond-raised catfish. Thus, a relatively large database of practical information on which to formulate feeds is available. A summary of nutrient and energy requirements and levels recommended for catfish are provided in Table 4.

Protein and Essential Amino Acids

A continual supply of protein is needed throughout life to provide amino acids and nonspecific nitrogen necessary for maintenance, growth, health, and reproduction. Protein requirements for catfish are well defined. Catfish fry raised in the hatchery require about 50% protein; fingerlings of 2 inches and above raised in fertilized nursery ponds require 28–32% protein; and pond-raised food fish require 24% protein for optimum growth and feed efficiency. However, feeding food fish a higher level of protein increases fillet yield (Figure 1) and decreases fillet fat (Figure 2). This is because high dietary protein promotes muscle growth. Protein requirements are affected by several factors including water temperature, feed allowance, fish size, amount of nonprotein energy in the diet, protein quality, natural food availability, and management practices.

Amino acids are classified as either essential or nonessential. Essential amino acids must be supplied in the diet since they cannot be synthesized by animals or at least not in quantities sufficient to meet their requirement. On the other hand, nonessential amino acids can be synthesized. Catfish require the same 10 essential amino acids as other animals (Table 4). For catfish, these requirements are met by mixing a combination of different complementary protein feedstuffs and, if needed, lysine. Lysine is the first, perhaps the only, limiting amino acid in catfish feeds because food fish feeds are generally based on lysine-deficient plant feedstuffs. Catfish feeds inherently contain liberal amounts of nonessential amino acids. This is advantageous because energy is not expended for their synthesis and because some nonessential amino acids can be used to meet a part of the requirement for some essential amino acids. For example, cysteine can replace about 60% of the methionine, and tyrosine can replace about 50% of the phenylalanine.

Amino acid requirements for catfish are generally expressed as a percentage of the dietary protein. This method is used because it appeared the requirement remained constant as a percentage of protein as the amount of dietary protein changed. There are indica-

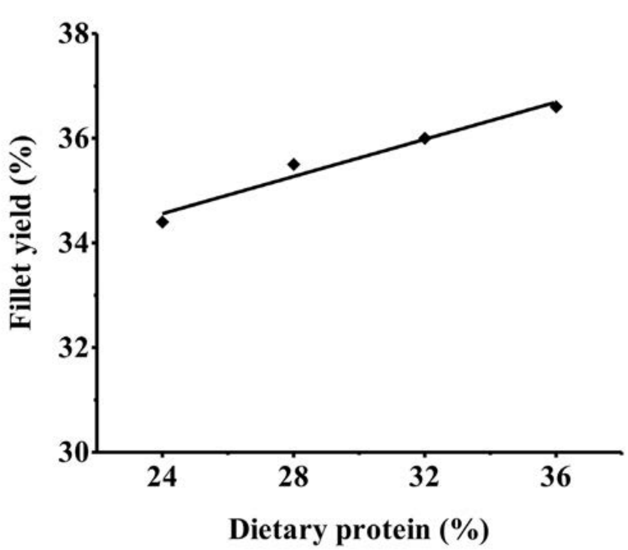

Figure 1. Relationship of dietary protein and catfish fillet yield.

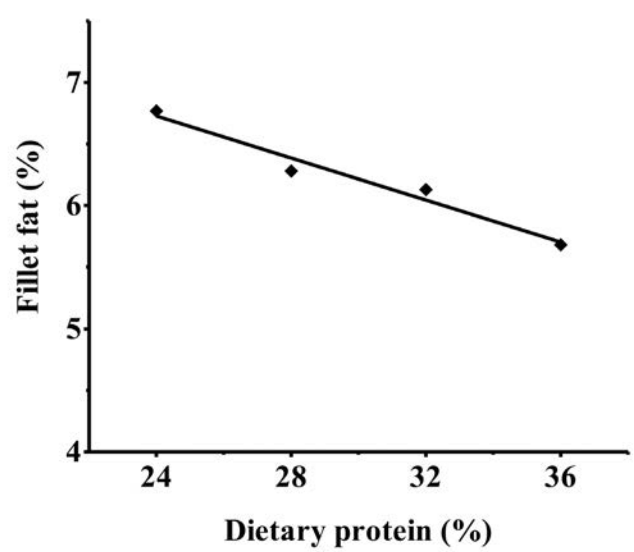

Figure 2. Relationship of dietary protein and catfish fillet fat.

Table 4. Nutrient requirements of catfish and recommended nutrient levels for catfish feeds.			
Nutrient	**Requirement[1, 2]**	**Recommended level (fingerlings)**	**Recommended level (food fish)**
Crude protein (%)			
Fingerlings (pond raised, 2 inch and above)	28–32	32	
Food fish (pond raised)	24	28	
Available essential amino acids (% of protein)		Same as requirement	Same as requirement
Arginine	4.3		
Histidine	1.5		
Isoleucine	2.6		
Leucine	3.5		
Lysine	5.0–5.1		
Methionine + cysteine	2.3		
Phenylalanine	5.0		
Threonine	2.0		
Tryptophan	0.5		
Valine	3.0		
Digestible energy/digestible protein ratio (kcal/g)			
Fingerlings		10.5	
Food fish			11
Fat (%)	Required	6–7	5–6
Essential fatty acids[3] (%)			
Linolenic acid (18:3 n-3) or	1–2		
n-3 long chain polyunsaturated fatty acids	0.5–0.75		
Starch (%)	Not required	20–25	20–25
Crude fiber[4] (%)		< 7	< 7
Vitamins (ppm, otherwise noted)			
A (IU/pound)	454–908	1,000	Same as fingerlings
D (IU/pound)	114–454	500	
E	25–50	50	
K	Required	5	
Thiamin	1	2	
Riboflavin	6–9	10	
Pyridoxine	3	5	
Pantothenic acid	10–15	15	
Niacin	7–14	None	
Biotin	Required	None	
Folic acid	1.5	2	
B_{12}	Required	0.01	
Choline	400	None	
Inositol	Not required	None	
Ascorbic acid	11–60	50–100[5]	
Minerals (ppm, otherwise noted)			
Calcium (%)	0.45[6]	None	None
Phosphorus (%)			
Fingerlings	0.33–0.42	0.4	
Food fish	0.3		0.35
Magnesium (%)	0.04	None	Same as fingerlings
Sodium and chloride	Required	None	
Potassium (%)	0.26	None	
Iron	30	30	
Copper	5	5	
Manganese	2.4	2.5	
Selenium	0.25	0.3	
Zinc	20	150	
Iodine	Required	2.5	
Cobalt	Required	0.05	
Chromium	Not known	None	

[1] Source: National Research Council. 1993. Nutrient requirements of fish. National Academy Press, Washington, D.C.
National Research Council. 2011. Nutritional requirements of fish and shrimp. National Academy Press, Washington, D.C.
[2] Requirement values were determined for catfish fingerlings unless otherwise noted.
[3] It appears essential fatty acids presented in dietary ingredients and supplemental animal fats/oils can meet the requirements.
[4] Fiber facilitates the passage of food through the digestive tract and aid in digestion; 5% crude fiber is optimum for catfish growth.
[5] 50 ppm if stabilized (phosphorylated) form of ascorbic acid is used; 100 ppm if crystalline or coated form of ascorbic acid is used.
[6] Determined in calcium-free water.

tions this might not hold for high-protein feeds. There is also debate as to whether or not it would be better to express these requirements as a percentage of the diet or as an amount of amino acid per unit of digestible energy. To ensure the diet contains adequate essential amino acids, we recommend amino acid requirements for catfish continue to be expressed as a percentage of the dietary protein.

Lipids and Essential Fatty Acids

Lipids (fats and oils) are a group of organic compounds including triglycerides, cholesterols, steroids, and other water-insoluble compounds. They are important because they are a highly digestible source of energy, supply essential fatty acids, serve as a vehicle for absorption of fat-soluble vitamins and other nutrients, act as precursors for steroid hormones, are major components of cell membranes, and help fish maintain neutral buoyancy in water. Dietary lipids can also affect the flavor of edible tissue.

Based on their chemical structure, fatty acids are classified either as saturated or unsaturated. Unsaturated fatty acids are further classified into n-3 (omega-3), n-6 (omega-6), etc. In general, n-3 and n-6 fatty acids or some combination of the two appear to be essential in animal diets. Catfish can synthesize n-3 long-chain polyunsaturated fatty acids (n-3 LCPUFAs) from linolenic acid, and thus their fatty acid requirement can be met by either 1–2% linolenic acid or 0.5–0.75% n-3 LCPUFAs. Natural food organisms found in ponds are a good source of essential fatty acids, particularly for small catfish fingerlings. Lipids inherent in feedstuffs along with a small amount of supplemental fat serve as the primary source of these nutrients. Catfish do not appear to require lipid beyond that needed to supply essential fatty acids. However, supplemental lipids are a good source of nonprotein energy and aid in feed processing. Lipid levels in commercial catfish feeds are generally less than 6%.

Carbohydrates

Carbohydrates include sugars, starches, cellulose, lignin, and other closely related substances found in plants. Small amounts of carbohydrate are stored in animals, either in the blood as glucose or in the liver and muscle tissues as glycogen. The ability to use dietary carbohydrates (starch and sugars) as an energy source differs greatly among fish species. Most freshwater and warmwater fish can use higher levels of dietary carbohydrate than coldwater or marine fish. Also, herbivores and omnivores digest starch better than carnivores. These differences are largely due to the levels of amylase and maltase present in the intestine. Catfish can digest about 78% of starch in cooked corn. However, use of simple sugars (glucose, fructose, sucrose, etc.) is not as efficient. Catfish metabolize glucose like mammals, but at a much slower rate because they lack enzymatic or endocrine systems capable of rapid metabolism of glucose. Catfish do not have a dietary requirement for carbohydrate since they can synthesize it from lipid and protein. However, dietary starch is beneficial as it supplies nonprotein energy and aids in feed manufacture. Catfish feeds typically contain relatively high levels (20–25%) of starch from grains and grain by-products.

Vitamins

Vitamins are a diverse group of organic substances required in small quantities in the diet for numerous functions related to nutrition and health. They are classified into fat-soluble and water-soluble vitamins. Fat-soluble vitamins include vitamins A, D, E, and K. Water-soluble vitamins consist of thiamin (B-1), riboflavin (B-2), pyridoxine (B-6), cyanocobalamin (B-12), biotin, choline, folic acid, inositol, niacin, pantothenic acid, and ascorbic acid (C). Each vitamin performs a specific metabolic function (Table 5). Microbes in the catfish intestine can synthesize vitamin B-12, and when exposed to sunlight, catfish can synthesize vitamin D in the skin. Qualitative and quantitative vitamin requirements for catfish have been well defined (Table 4). Vitamin deficiencies are rarely encountered in natural populations of fish or in pond-raised catfish. Characteristic vitamin deficiency signs can be induced in catfish raised in the laboratory by feeding vitamin-deficient diets (Table 6).

Minerals

Catfish generally require the same 14 minerals for skeletal structure, growth, and various metabolic functions as other animals (Table 5). They also require sodium, potassium, and chloride for osmotic balance between body fluids and the aquatic environment. Depending on the amount required, minerals are generally classified as major or trace minerals. Major minerals include sodium, potassium, chloride, calcium, magnesium, and phosphorus. Trace minerals include iron, copper, zinc, manganese, selenium, cobalt, iodine, and chromium. Fish can absorb dissolved minerals from the water. For example, if the water contains adequate calcium, catfish can meet their calcium requirement. Soluble phosphorus in ponds is typically very low, so phosphorus must be provided in the diet. Quantitative requirements and deficiency signs of various minerals have been determined for catfish (Tables 4 and 6).

Energy

Quantitatively, energy is the most important component of the diet because most farmed animals are fed *ad libitum* (i.e., have constant access to feed), and feed intake is controlled by dietary energy. Since catfish are not fed in this way, feed intake is more of a function of feed allowance than dietary energy except when they are fed to satiety. Catfish require less energy than terrestrial animals for protein synthesis, for tissue maintenance, to maintain their spatial position, to excrete nitrogenous waste, and to assimilate ingested food. Energy requirements for catfish are based on digestible energy values of feedstuffs determined by *in vivo* digestibility trials. They are best expressed as a ratio of digestible energy to digestible protein (DE/DP). This is important, primarily because a deficiency of nonprotein energy will result in protein being used for energy, or, if energy is too high, excessive fat may be stored in the visceral or muscle tissue. It appears a DE/DP ratio of about 10.5 is optimum for pond-raised catfish fingerlings and about 11 for food fish.

Table 5. Main metabolic functions of vitamins and minerals

Vitamin or mineral	Roles played in metabolic functions
Vitamin A	Formation of visual purple in the retina of eye, development and maintenance of epithelium cells, embryo development.
Vitamin D	Absorption of calcium in intestine, maintaining calcium homeostasis, bone development.
Vitamin E	Antioxidant working along with selenium and vitamin C in preventing phospholipids from oxidation in cell membranes.
Vitamin K	Synthesis of blood clotting proteins, bone development.
Thiamin (B-1)	Component of coenzyme in metabolic processes to generate energy.
Riboflavin (B-2)	Component of coenzymes involved in oxidation-reduction reactions in metabolism of keto acid, fatty acids, and amino acids.
Pyridoxine (B-6)	Component of coenzymes involved in amino acid metabolism, synthesis of neurotransmitters.
Pantothenic acid	Component of coenzyme in reactions in the energy-yielding cycle involved in the metabolism of glucose, fatty acids, and amino acids, synthesis of fatty acids.
Niacin	Component of coenzymes in oxidation-reduction reactions in carbohydrate, lipid, and amino acid metabolism, energy generation.
Biotin	Part of coenzyme involved in CO_2 metabolism and synthesis of long-chain fatty acids and purines.
Folic acid	Precursor of coenzyme involved in various reactions in metabolism and synthesis of certain amino acids and synthesis of purines and pyrimidines (building blocks of DNA and RNA), blood cell formation.
Vitamin B-12	Component of coenzymes in fatty acid metabolism and synthesis of methionine, development and maturation of red blood cells, folic acid metabolism.
Choline	Component of phospholipid found in cell membranes, precursor of neurotransmitter, synthesis of methionine.
Vitamin C	Collagen synthesis in bone and connective tissues, wound healing, antioxidant along with vitamin E to prevent lipid peroxidation, iron absorption.
Calcium	Component of bone, muscle function, nerve impulse transmission, blood clotting, osmoregulation, cofactor of enzymatic processes.
Phosphorus	Component of bone, phospholipids, coenzymes, DNA, and RNA, serving as a buffer (inorganic phosphate) to maintain normal pH in cellular fluids.
Magnesium	Component of bone, cofactor of enzymatic reactions, cellular respiration, neuromuscular transmission, metabolism of carbohydrates, lipids, and proteins.
Sodium, potassium, and chloride	Osmoregulation between body fluid and aquatic environment, maintaining acid-base balance.
Iron	Production and normal functioning of hemoglobin, myoglobin, and enzyme systems.
Copper	Formation of blood cells, component of copper-dependent enzymes in oxidation-reduction reactions, collagen maturation, iron absorption and metabolism, hemoglobin formation.
Manganese	Cofactor of enzyme systems in metabolism of glucose, fatty acids, and amino acids.
Selenium	Component of enzyme which along with vitamin E protects phospholipids in cell membranes from oxidation.
Zinc	Cofactor of zinc-dependent enzymes in metabolism of carbohydrates, lipids, amino acids, and nucleotides.
Iodine	Component of thyroid hormones which regulate metabolic rates.
Cobalt	Component of vitamin B-12.
Chromium	Component of glucose tolerance factor in carbohydrate metabolism, lipid metabolism.

Sources: Halver, J.E., and R.W. Hardy. 2002. Fish nutrition, third edition. Academic Press, New York, NY.
National Research Council. 1993. Nutrient requirements of fish. National Academy Press, Washington, D.C.
National Research Council. 2011. Nutritional requirements of fish and shrimp. National Academy Press, Washington, D.C.

Table 6. Vitamin and mineral deficiency signs reported for catfish.	
Vitamin or mineral	**Deficiency signs[1,2]**
Vitamin A	Exophthalmia ("popeyes"), edema, hemorrhage in kidney, skin depigmentation.
Vitamin D	Low body ash, calcium, and phosphorus.
Vitamin E	Muscular dystrophy, exudative diathesis (inflammation of skin and mucus membranes), skin depigmentation, hemolysis, hemosiderosis (iron overloading) in spleen and pancreas, fatty liver, ceroid (yellow lipid deposit).
Vitamin K	Skin hemorrhage.
Thiamin (B-1)	Loss of equilibrium, nervousness, dark skin color.
Riboflavin (B-2)	Short-body dwarfism.
Pyridoxine (B-6)	Greenish-blue coloration, tetany, nervous disorders, erratic swimming.
Pantothenic acid	Clubbed gills, emaciation, anemia, eroded skin.
Niacin	Skin and fin lesions, exophthalmia, deformed jaws, anemia.
Biotin	Hypersensitive, skin depigmentation, reduced biotin-dependent enzyme activity in liver.
Folic acid	Anemia.
Vitamin B-12	Anemia.
Choline	Fatty liver, hemorrhage in kidney and intestine.
Vitamin C	Scoliosis, lordosis, internal and external hemorrhage, fin erosion, reduced bone collagen.
Calcium	Reduced bone ash.
Phosphorus	Reduced bone ash, calcium, and phosphorus.
Magnesium	Sluggishness, muscle flaccidity, and reduced body magnesium.
Potassium	None.
Copper	Reduced copper-dependent enzyme activity
Iron	Reduced hemoglobin, hematocrit, red blood cell count, and serum iron and transferrin saturation levels.
Manganese	None.
Selenium	Reduced liver and plasma selenium-dependent enzyme activity.
Zinc	Reduced serum zinc and zinc-dependent enzyme activity, reduced bone zinc and calcium.

[1] Sources: National Research Council. 1993. Nutrient requirements of fish. National Academy Press, Washington, D.C.
National Research Council. 2011. Nutritional requirements of fish and shrimp. National Academy Press, Washington, D.C.
[2] Common deficiency signs are reduced feed intake and growth.

Undesirable Dietary Components and Toxins

In addition to essential nutrients, catfish feeds contain or may contain other naturally occurring substances not desirable or even toxic to the animal. These include, but are not limited to, fiber, pigments, oxidized oil, antinutrients, and mycotoxins.

Fiber

Fiber is a nonnutritive dietary component indigestible by fish. Even though it is generally undesirable in catfish feeds, it serves as a source of bulk facilitating the passage of food through the digestive tract. It is inherent in plant-based feedstuffs and includes lignin, cellulose, hemicelluloses, pectin and gums, and other polysaccharides. Crude fiber is typically used to describe the fiber content of feedstuffs and catfish feeds. However, crude fiber represents only a small portion of the total non-utilizable carbohydrates. There are other measures of dietary fiber that may be more appropriate. For example, total dietary fiber (TDF) more accurately reflects the level of indigestible carbohydrates found in feedstuffs. In catfish, as dietary TDF levels increased, weight gain was quadratic increasing up to 23% dietary TDF (5% crude fiber) and then decreasing (Figure 3). Feed conversion ratio increased linearly as dietary fiber levels increased (Figure 4). The maximum level of dietary fiber in catfish feeds should not exceed about 32% TDF or 7% crude fiber.

Pigments

Catfish typically have a white flesh that consumers prefer, but on occasion yellow pigmentation may be visible. This is mainly caused by the yellow pigments, mostly lutein and zeaxanthin, which are inherent in certain feedstuffs as well as some natural food items found in ponds. Concentrations of these pigments in various feedstuffs are corn, 15 ppm; corn germ meal, 3 ppm; corn gluten feed, 13 ppm; corn distillers dried grains with solubles, 20–40 ppm; corn gluten meal, 330 ppm; and canola meal, 15 ppm. Commercial catfish feeds typically contain levels much lower than the 7 ppm necessary to cause yellow coloration. Thus, feed is seldom the issue. The problem appears to be due to the intake of food items found in catfish ponds. Two factors suggest this is the case. First, natural foods contain yellow pigments; some contain high levels. For example,

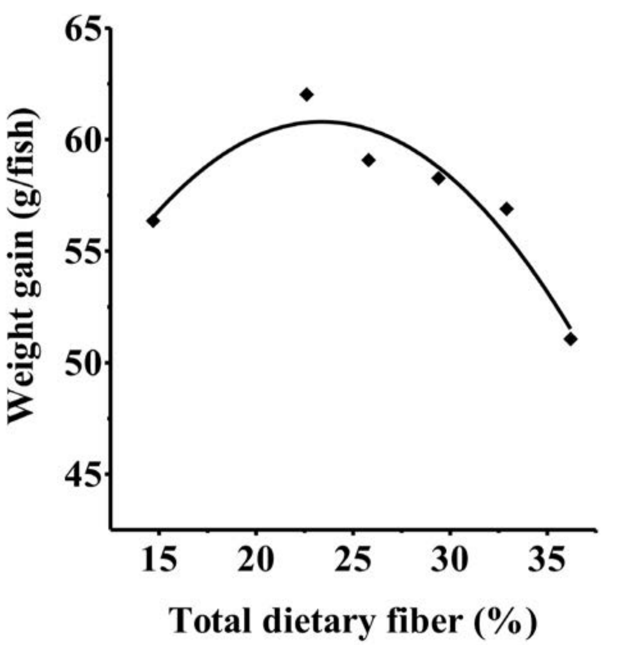

Figure 3. Relationship of total dietary fiber and catfish weight gain.

gizzard shad contain 0.9 ppm; threadfin shad, 4.9 ppm; green sunfish, 9.7 ppm; snails, 54 ppm; and filamentous algae, 154 ppm lutein plus zeaxanthin on wet-tissue basis. Second, the occurrence of these pigments in catfish seems to be more prevalent when fish are either not fed or severely underfed, and thus are more likely to consume natural foods. Given time, these pigments will purge from the tissue, particularly when fish are being fed daily. But it will take some time, about 2 months at temperatures 68–86 °F and more than 3 months at 50 °F.

While yellow pigments may negatively affect the marketability of catfish fillets, they may be beneficial to human health. Lutein and zeaxanthin are found in high concentrations in the retina of the eye and are thought to reduce the risk of blindness (age-related macular degeneration) and protect the eye from intensive light. Their potent antioxidant activity may improve the health of the skin and other tissues by helping protect tissues from free radicals.

Oxidized Oil

Fats and oils, especially marine fish oils, containing high levels of polyunsaturated fatty acids, are easily oxidized to form free radicals and peroxides that can cause cellular oxidative stress. Catfish fed oxidized marine fish oil (≥ 3%) show reduced protein and energy digestibility, reduced growth and feed efficiency, and histological changes in kidney and liver. Oxidation is not generally an issue because supplemental lipids used in catfish feeds are stabilized with antioxidants.

Antinutrients

Antinutrients refer to naturally occurring compounds in feed ingredients interfering with digestion, absorption, or metabolism of nutrients in an animal. Several antinutrients may be found in various feedstuffs; however, most are generally not a problem to catfish. Those most relevant to catfish include phytic acid, protease inhibitors, and gossypol.

Phytic Acid — Approximately two-thirds of phosphorus in plant seeds is bound in phytic acid or phytate. Phytate-phosphorus is largely unavailable to simple-stomach animals including catfish. Phytic acid can bind with other minerals such as iron and zinc making them less available and can also form a complex with protein. Phytase, an enzyme produced by fungi or bacteria, can break the bonds in the phytate molecule and release inorganic phosphorus that is readily absorbed by catfish (see the *Feed Additives* section for more details).

Protease Inhibitors — Trypsin inhibitor and other protease inhibitors are components found in the seeds of many legume plants including soybeans. They inactivate the pancreatic enzyme trypsin by forming irreversible complexes with the enzyme. These inhibitors are generally deactivated by the heat encountered during the extraction of oil from soybeans. In addition, they are further degraded by the high heat used in the manufacture of floating catfish feeds. For example, raw soybeans contain about 45–50 mg/g, soybean meal 5–8 mg/g, and extruded catfish feeds < 1 mg/g trypsin inhibitor. Dietary levels should not exceed 3.2–3.6 mg/g trypsin inhibitor.

Gossypol — Gossypol is a fat-soluble, yellow compound found in the pigment glands of cotton plants either in a bound or free form. Bound gossypol, which binds with free amino groups in protein, is generally of little significance to catfish except it reduces the availability of amino acids, especially lysine. Free gossypol is toxic to simple-stomach animals and can cause a wide array of issues including reduced feed intake and growth. Catfish can tolerate up to 900 ppm of dietary free gossypol. Free gossypol causes infertility in humans and other animals, but catfish brooders do not appear to be affected.

Mycotoxins

Mycotoxins are toxic compounds produced by certain fungal or mold species, such as *Aspergillus sp., Fusarium sp.,* and *Penicillium sp*. Under favorable conditions (high moisture and warm temperature), these fungi can grow on various crops before and after harvest and during storage. Most mycotoxins are heat stable and remain active after feed processing. Toxic effects of mycotoxins in animals include reduced feed intake and growth, tissue lesions, cancer, and death. Since catfish feeds are composed primarily of plant feedstuffs, mycotoxins can be an issue. Feedstuffs should be screened for suspected mycotoxin contaminations before use. This can be done at the feed mill or commercial labs using an enzyme linked immunosorbent assay (ELISA) kit.

Aflatoxins — Aflatoxins produced by *Aspergillus flavus* and *Aspergillus parasiticus* are widespread and potent carcinogens. Aflatoxin B_1 is most prevalent and is commonly found in contaminated peanut, corn, and cottonseed. Catfish can tolerate high levels of aflatoxin. Early reports indicated high concentrations of purified aflatoxins (2,000 ppb) in the diet did not adversely affect catfish. A recent report using moldy corn (naturally occurring aflatoxins) showed dietary aflatoxin levels up to 220 ppb did not affect weight gain, FCR, hematocrit, or liver morphology of catfish. Dietary aflatoxin levels are reduced by about 60% during the manufacture of commercial catfish feeds. The legal limit for total aflatoxins set by the United States Food and Drug Administration (FDA) is 20 ppb for "other animal species," which is assumed to include fish and the limit is followed for catfish feeds.

Ochratoxins — Ochratoxins are produced by *Aspergillus sp*. and *Penicillium sp*. Ochratoxin A is most prevalent and is commonly found in contaminated cereal grains like corn and wheat, soybeans, and peanuts. Catfish appear to be sensitive to ochratoxin A, tolerating only 0.5 ppm in the diet. Dietary ochratoxin A levels of ≥ 1 ppm depress growth and causes histopathological lesions in the posterior kidney and liver, and ≥ 8 ppm reduce hematocrits and survival.

Fusarium Toxins — *Fusarium sp*. can produce several mycotoxins, including fumonisins, moniliformin, vomitoxin (deoxynivalenol, DON), T-2 toxin, diacetoxyscirpenol (DAS), and zearalenone. These toxins are commonly found in contaminated cereal grains such as corn, wheat, barley, and sorghum (milo). Fusarium toxins that have been evaluated in catfish can affect growth and feed conversion and can cause severe molecular damage if consumed in high enough levels. However, they are generally found in catfish feeds below the threshold that causes major issues. Levels of these toxins catfish can tolerate are as follows: fumonisin B_1, 10 ppm; moniliformin, < 20 ppm; vomitoxin, 10 ppm; and T-2 toxin, < 0.625 ppm.

FEEDS

The nutrient requirements of farmed catfish are met by feeding a feed providing energy and nutrients in the proper proportions necessary for rapid weight gain and good feed efficiency, processing yield, and product quality. Since feed cost typically represents about one-half of the variable production costs, catfish feeds should be formulated to be cost-effective. This can be achieved by carefully selecting and mixing traditional feedstuffs with less expensive alternative feedstuffs and nutrient supplements.

Feed Ingredients

Feedstuffs should be digestible, easily handled, able to withstand the rigors of the manufacturing process, available consistently, and economical. Feedstuffs are generally classified into either protein or energy feedstuffs. Those containing ≥ 20% protein are considered as protein feedstuffs, and those containing < 20% protein as energy feedstuffs. Protein feedstuffs are further divided as either animal or plant. Proximate composition, digestible energy, and digestible/available nutrients of feedstuffs commonly used in catfish feeds are presented in Table 7.

Protein Feedstuffs — Though generally of higher quality than plant-based feedstuffs, animal proteins are used sparingly for catfish feeds because they are expensive. Except for soybean meal, commonly used plant proteins are typically deficient in lysine. But this can be compensated for by using supplemental lysine. Soybean meal and cottonseed meal are the primary protein feedstuffs used in catfish feeds. Other oilseed meals (peanut meal, canola meal, etc.) can be used, but they are usually either not available consistently or are not economical.

Soybean meal is obtained by grinding the flakes after most of the oil in soybean seeds has been removed. Solvent-extracted soybean meal with hulls contains about 44% protein, and dehulled meal contains 47% protein. Dehulled soybean meal is generally used in catfish feeds. Soybean meal has the best amino acid profile

Table 7. Dry matter, digestible energy, crude protein, crude fat, crude fiber, phosphorus, lysine, total sulfur-containing amino acids (methionine + cysteine), and yellow pigments (lutein + zeaxanthin) of feedstuffs used in catfish feeds, as fed basis.[1, 2]

Feedstuff	Dry matter %	Digestible energy kcal/kg	Crude protein %	Crude fat %	Crude fiber %	Ash %	Phosphorus %	Lysine %	Methionine + cysteine %	Yellow pigments[5] ppm
Soybean meal, dehulled, solvent (47%[3])	88	3,344	47 (44.3)	2.0	3.0	6.0	0.72 (0.26)	3.02 (2.83)	1.41 (1.27)	—
Cottonseed meal, prepress solvent (41%)	90	2,365	41 (33.6)	1.5	12.7	6.4	1.00 (0.22)	1.65 (1.09)	1.16 (0.84)	—
Peanut meal, solvent (47%)	90	3,283	47 (37.6)	2.5	8.4	5.0	0.57	1.52 (1.31)	1.10 (0.93)	—
Canola meal, solvent (38%)	91	2,234	38 (29.2)	3.8	11.1	7.2	1.20	2.02 (1.59)	1.74 (1.41)	15
Distillers dried grains with solubles[4] (29%)	88	2,707	29 (25.2)	7.0	7.0	5.5	0.87 (0.67)	0.94 (0.68)	1.20 (1.00)	20–40
Fish meal, menhaden (62%)	92	4,099	62 (55.6)	9.2	1.0	19.0	3.00 (1.28)	4.70 (4.46)	2.20 (1.99)	—
Porcine meat and bone meal[5] (52%)	95	3,716	52 (41.8)	11.3	—	23.0	4.50	2.92 (2.47)	1.31 (0.86)	—
Poultry by-product meal (57%)	94	4,136	57 (51.6)	14.0	2.5	17.0	2.70	2.25 (2.03)	1.81 (1.78)	—
Corn germ meal	90	2,334	20 (16.7)	1.0	12.0	3.8	0.50	0.90 (0.70)	1.00 (0.79)	3.4
Corn gluten feed	88	2,165	21 (15.7)	2.0	10.0	7.8	0.90 (0.67)	0.60 (0.40)	1.00 (0.71)	13
Corn grain, yellow	86	2,362	7.5 (6.1)	3.5	1.9	1.1	0.28 (0.08)	0.24 (0.17)	0.36 (0.22)	13
Wheat middlings	89	2,342	15 (12.8)	3.6	8.5	5.5	1.17 (0.24)	0.70 (0.60)	0.31 (0.24)	—
Wheat grain	88	2,398	13.5 (11.9)	1.9	3.0	2.0	0.41	0.40	0.55	—
Dicalcium phosphate	—	—	—	—	—	85.6	18.5 (13.0)	—	—	—
Monocalcium phosphate	—	—	—	—	—	83.2	21.0 (17.0)	—	—	—
Fish oil, menhaden	99	9,099	—	99	—	—	—	—	—	—

[1] Unless otherwise noted, values are from Fowler, J. 2019. Feedstuffs ingredient analysis table, 2019-2020 edition (https://www.feedstuffs.com).
[2] Values in parentheses are digestible or available nutrients. Digestible energy and digestible/available nutrients are calculated values. See footnote 1 in Tables 2 and 3 for sources.
[3] See footnote 2 in Table 1.
[4] From corn.
[5] Analyzed in-house.

of all common plant protein sources. It is also highly palatable and digestible to catfish. Up to 50% soybean meal has been used in commercial catfish feeds without detrimental effects.

Cottonseed meal is the ground material from the cake or flakes after most of the oil has been extracted from cottonseed. Oil can be removed by various methods, but prepress (expander) solvent extraction is the most common method. Cottonseed meal contains 41% protein and is highly palatable to catfish. It contains free gossypol and cyclopropene fatty acids which can be toxic, but not at levels typically found in catfish feeds. Cottonseed meal is used in catfish feeds at about 10–25%.

Peanut meal is the product attained by grinding the cake after most of the oil has been extracted from shelled peanuts. Solvent-extracted peanut meal contains 47% protein, and the mechanically extracted meal contains 45% protein. Peanut meal is highly palatable to catfish and can be used up to 25% in catfish diets. It is seldom used because it is not widely available, and it is prone to contamination by aflatoxins.

Canola meal is the product prepared from a special rapeseed variety after most of the oil has been removed. Compared with typical rapeseed meal, canola meal contains much lower levels of the toxic compounds erucic acid and glucosinolate. Canola meal contains 38% protein. It contains less lysine than soybean meal but more lysine than cottonseed meal and peanut meal. Up to 25% canola meal can be used in catfish feeds. It is rarely used because it is not available locally and often not cost-effective.

Distillers dried grains with solubles (DDGS) is the product obtained by drying the materials remaining after almost all starch in grains, typically corn in the United States, is converted to ethanol. This product contains 27% protein and 9% oil. The "low oil" product contains 29% protein and 7% oil. The high oil content limits its use in catfish feeds as does the relatively high concentration of yellow pigments (20–40 ppm). About 10–15% DDGS may be used in catfish feeds.

Fish meal is the dried, ground tissues of undecomposed whole fish, fish cuttings, or both with and without the extraction of the oil. The most commonly available fish meal in the United States is menhaden meal, which contains 62% protein of excellent quality and 9% oil, a rich source of essential fatty acids and energy. It is also an excellent source of phosphorus and other minerals. However, fish meal is expensive, and the supply is limited. It is not used in catfish food fish feeds, but catfish fry feeds used in the hatchery and some fingerling feeds contain fish meal.

Porcine meat and bone meal is the rendered product from pork processing, excluding blood, hair, hoof, hide trimmings, stomach contents, and manure except in small amounts as may be unavoidable. It contains 52% crude protein and 11% fat, and its protein quality is comparable to soybean meal. It is a good source of phosphorus and other minerals. Porcine meat and bone meal is generally used at 5–8% in catfish feeds.

Porcine meat and bone/blood meal blend is a mixture of meat and bone meal and blood meal from the pork processing industry. The two feedstuffs are blended to mimic the nutritional profile of menhaden meal (at least the lysine content) and provides 65% protein. This product is used similarly to porcine meat and bone meal.

Bovine meat and bone meal, bovine meat and bone/blood meal blend are by-products from the beef processing industry, having similar nutrient profiles as porcine by-products. These products were once routinely used in catfish feeds but are no longer used because of their association with "mad cow" disease.

Poultry by-product meal consists of the ground, rendered parts of the carcass of slaughtered poultry, including necks, feet, undeveloped eggs, and intestines, but excluding feathers except in unavoidable small amounts. Feed-grade poultry by-product meal contains 57% protein, and its protein quality is similar to porcine meat and bone meal or soybean meal. However, its use in catfish feeds is limited because of its sporadic availability and higher price.

Hydrolyzed poultry feathers (hydrolyzed feather meal) results from the treatment (under pressure) of undecomposed feathers from slaughtered poultry. By definition, at least 75% of its crude protein must be digestible based on pepsin digestibility. The product is high in protein (85%) but deficient in some EAAs, especially lysine. It is rarely used in catfish feeds because of its poor quality and palatability. A dietary level of 5% has been shown to reduce feed intake in catfish.

Energy Feedstuffs — Grains and grain by-products are the primary and least expensive energy sources used in commercial catfish feeds. Lipids also provide energy, but catfish feeds contain rather low levels of fat.

Corn grain has traditionally been the main energy source in catfish feeds. But, because its price has increased considerably, less corn is used today. Corn is low in protein (7.5%) but high in starch (63%). A minimum of 15–20% corn is typically included in catfish feeds to provide energy and to aid in feed manufacturing.

Wheat grain contains 13% protein and 57% starch. It is a good energy source and pellet binder. Because it is more expensive than corn, it is seldom used in catfish feeds.

Sorghum grain "Milo" contains 11% protein and 66% starch. Some varieties contain high levels of tannins, reducing its palatability to some animals. This does not appear to be an issue with catfish. Sorghum is rarely used in catfish feeds because it is generally not available.

Wheat middlings, a by-product of wheat milling, consist of fine particles of wheat bran, shorts, germ, flour, and some of the offal. The by-product contains 15% protein and 33% starch. Depending on price, it is used to replace part of corn in catfish feeds. Wheat middlings can be used up to 25% of the feed. In humid areas such as the Mississippi Delta, using higher levels may cause the feed pellets to stick together.

Corn gluten feed is part of the shelled corn remaining after the extraction of most of the starch, gluten, and germ. It typically contains 21% protein and 15% starch. By definition, it is considered as a protein feedstuff, but it is mainly used to replace energy feedstuffs in catfish feeds. It is usually competitively priced relative to corn and wheat middlings. Up to 30% of corn gluten feed can be used in catfish feeds without detrimental effects. Corn gluten feed contains a level of yellow pigments comparable to corn.

Corn germ meal is ground corn germ with most of the oil removed. It contains 20% protein and 17% starch. It has a lower level of yellow pigments than corn and corn gluten feed. Corn germ meal can be used interchangeably with corn gluten feed in catfish feeds.

Rice bran is the bran layer and germ of the rice including some broken rice and unavoidable small amounts of hull fragments. It contains 13.5% protein, 6% fat, and 26% starch. No more than 5% of full-fat rice bran is recommended for catfish feeds. Higher levels (up to 15%) of the solvent-extracted and stabilized rice bran can be used. Rice bran is rarely used in catfish feeds because of its sporadic availability, and it has been reported it is highly abrasive causing excess wear to feed processing equipment.

Fats and oils from animals or plants are highly concentrated energy sources and contain essential fatty acids and fat-soluble vitamins. Animal fats and oils that have been used in catfish feeds include catfish offal oil, menhaden oil, and poultry fat. Plant oils can be used but are generally too expensive. Supplemental fat/oil (1–2%) is typically sprayed on the finished feed pellet. There is evidence adding supplemental marine fish oils or algal products to the feed increases n-3 fatty acid concentrations in catfish. While it is perhaps desirable from a

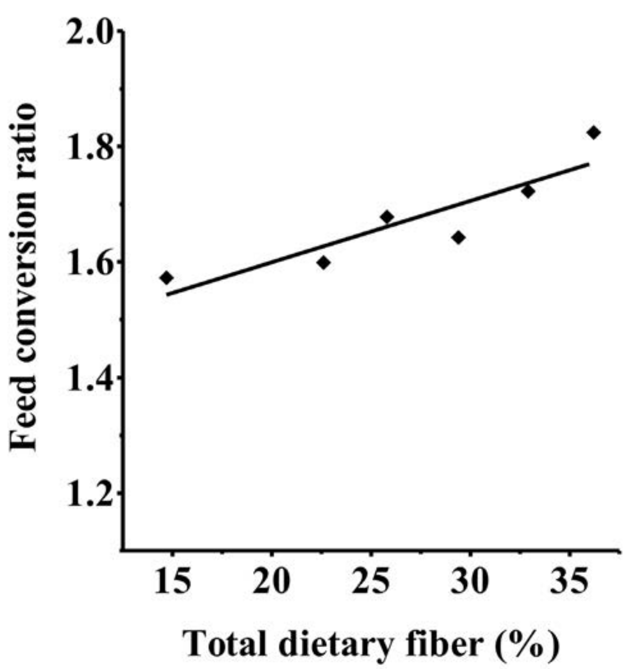

Figure 4. Relationship of total dietary fiber and catfish feed conversion ratio.

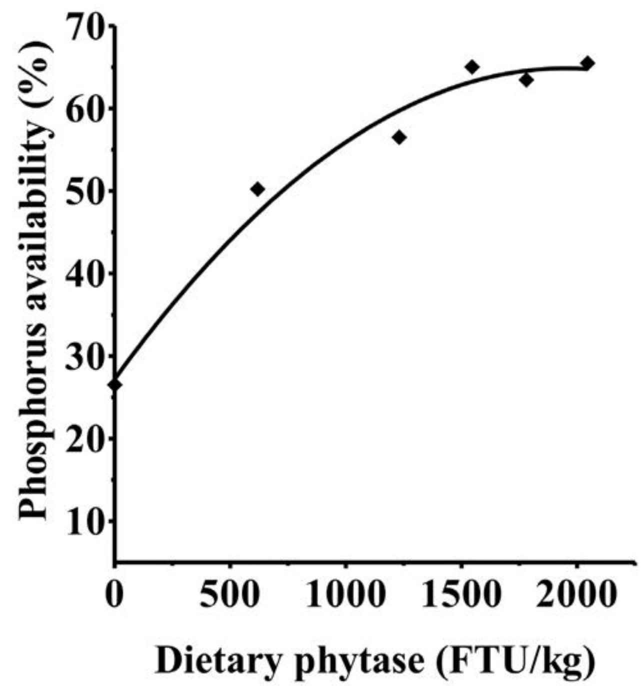

Figure 5. Relationship of dietary phytase and phosphorus availability for catfish.

nutritional view, in practice, it significantly increases production costs that cannot be recovered in the marketplace.

Supplemental Amino Acids — Though there is continued debate on the use of amino acid supplements by fish, catfish can efficiently use supplemental amino acids. In practice, lysine is the only supplemental amino acid needed in commercial catfish feeds. Its use is a relatively recent practice that began with the use of alternative feedstuffs to replace soybean meal and animal proteins. Supplemental lysine is commonly used up to 0.5% of the diet.

Vitamin and Mineral Premixes — Catfish feeds are supplemented with a premix containing vitamins in quantities necessary to meet dietary requirements and to compensate for losses during feed processing. The post feed-manufacturing retention rates for vitamins are as follows: ascorbic acid (vitamin C), 65%; phosphorylated vitamin C, 83%; vitamin A acetate, 65%; thiamin, 67%; vitamin B-6, 70%; folic acid, 91%; niacin, 96%; and vitamin E acetate, riboflavin, and pantothenic acid, 100%. Biotin, choline, and niacin supplements are not necessary because they are abundant in feedstuffs. Even though the phosphorylated vitamin C is highly stable, it is generally less expensive to use an excess of regular ascorbic acid to compensate for losses. Vitamin C can be degraded during feed storage, but this is not usually a concern in major catfish-growing regions where feed is only stored for a short time. However, if the feed is to be stored for an extended time using phosphorylated vitamin C is recommended.

Phosphorus (typically mono- or dicalcium phosphate) and a trace mineral supplement are added to catfish feeds to ensure all mineral requirements are met. A phosphorus supplement is not necessarily needed if phytase is used (see *Feed Additives*). Trace mineral premixes typically contain inorganic iron, copper, manganese, zinc, selenium, iodine, and cobalt to meet or exceed the requirements.

Feed Additives — Feed additives are used in animal feeds to improve feed quality, to enhance performance, and to improve health. While several additives have been evaluated for catfish, only antioxidants and microbial phytase are used in commercial catfish feeds.

Antioxidants are compounds that slow the oxidation of sensitive nutrients. Some antioxidants, such as vitamins C and E, are naturally occurring. Polyunsaturated lipids are sensitive to oxidation, which generate highly reactive and destructive peroxides and free radicals of oxygen. Oxidation can be limited by using vitamin E or

Table 8. Restrictions for least-cost formulation of a 28% protein feed for catfish food fish.		
Nutrient or feedstuff	**Minimum**	**Maximum**
Crude protein (%)	28	28
Crude fat (%)	—	6
Crude fiber (%)	—	7
Digestible energy (kcal/g)	2.6	2.8
Available lysine (%)	1.4	—
Available methionine + cysteine (%)	0.65	—
Available phosphorus (%)	0.35	—
Yellow pigments (lutein and zeaxanthin, ppm)	—	7
Soybean meal	20	—
Cottonseed meal	—	20
Distillers dried grains with solubles	—	15
Pork meat and bone meal or poultry by-product meal	—	10
Corn germ meal or corn gluten feed	—	30
Corn grain	15	—
Wheat middlings	—	25
Di- or monocalcium phosphate	Meet phosphorus requirement	
Vitamin premix	Meet all vitamin requirements	
Trace mineral premix	Meet all trace mineral requirements	
Fat/oil (sprayed on finished pellets to reduce dust)	1.5	1.5

synthetic antioxidants, such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and ethoxyquin. These compounds are added to fats and oils by the manufacturer. FDA limits are 0.02% of dietary fat for BHA and BHT, and 150 ppm of diet for ethoxyquin.

Enzymes: Most phosphorus found in plant feedstuffs is bound in phytic acid or phytate, which is unavailable. In an all-plant diet, phosphorus is only about 27% available to catfish. However, adding phytase at 500 phytase units (FTU)/kilogram to the diet improves availability to 44%. At 1,500 FTU/kilogram, phosphorus availability reaches a maximum of 63% (Figure 5). A dietary phytase level of 350 FTU/kilogram can liberate enough inorganic phosphorus (PO_4^{3-}) to meet the phosphorus requirement of pond-raised catfish, provided the diet has a total phosphorus level of ≥ 0.6%. Phytase cannot withstand the high temperature associated with the manufacture of floating feeds, so it must be sprayed on the finished feed. To ensure adequacy, 500 FTU/kilogram of diet is recommended in catfish feeds. There may be some benefits to using very high doses of phytase (superdosing) in animal feeds. Reports from the swine and poultry industries indicate high levels of phytase (2,500–5,000 FTU/kilogram of diet) further improves feed consumption, growth, feed conversion, and absorption of phosphorus and other minerals. However, recent studies with hybrid catfish show no benefits of using these high doses.

Other additives: Dried algae *Schizochytrium sp*., a rich source of DHA (22:6 n-3), added at 1–1.5% in the diet, improved catfish growth and feed efficiency. Used at 2%, dried algae markedly increased 22:6 n-3 and total n-3 LCPUFAs in the edible tissue of fish. Diets containing 1–2% brewer's yeast *Saccharomyces cerevisiae* improved growth and feed efficiency of fingerling catfish under laboratory conditions. However, when it was fed to food-size hybrid catfish in ponds, no improvements were observed. Active components of the live yeast were likely degraded during the manufacturing of floating feeds. Other products that have been evaluated include bacterial concentrate (*Streptococcus sp.*), digestive enzymes (amylase, cellulase, and proteases), amino acid (methionine and arginine) supplements, amino acid derivatives (carnitine and taurine), cholesterol, dried garlic powder, sea salt, and Azomite® (hydrated sodium calcium aluminosilicate). None of these additives showed benefits in growth and feed efficiency in catfish, and currently are not used in commercial catfish feeds.

Feed Formulations

Catfish feeds are generally formulated using computer programs adopting a set of specifications (Table 8) to ensure that the feed meets nutrient and energy needs, the feed pellets are water stable and float on the water surface, and the feed is palatable, digestible, and cost-effective. However, this approach is limited because relatively few feedstuffs are suitable for use, catfish feed formulas are seldom changed during the growing season, and catfish feed mills have limited storage for feed ingredients. To formulate cost-effective feeds, the following information is needed:

- Nutrient and energy requirements of fish.
- Nutrient and energy concentrations of feedstuffs.
- Nutrient and energy digestibility/availability of feedstuffs.
- Cost and availability of feedstuffs.
- Nutrient and ingredient specifications or restrictions.

Feed Processing

Catfish feeds are manufactured using a highly organized system to procure, store, and process feed ingredients into extruded feed pellets. A photo of a typical catfish mill is shown in Figure 6, and a schematic representation of catfish feed processing is presented in Figure 7.

Procurement of Feed Ingredients — A designated purchasing manager works with various vendors and commodity brokers to procure raw ingredients. These purchases can be "spot purchases" or may be purchases booked months in advance. Specifications are prepared for each ingredient and may set minimum crude protein levels, maximum moisture content, bushel weight, etc., depending on the feed ingredient.

Receiving and Storage — Feed ingredients are shipped by rail cars or trucks. All ingredients are inspected for color, odor, and texture upon arrival before acceptance. Grain shipments are visually examined and tested for bushel weight and moisture content before unloading. Likewise, protein feedstuffs may be sampled for moisture, protein, and fat. Feedstuffs should be examined for the presence of foreign materials and for evidence of mold. Incoming weights of all commodity shipments received are determined and payments to brokers are based on these weights.

Grinding, Batching, and Mixing — Whole grains and grain by-products (particularly if pelleted) are ground through a No. 6 screen in a hammer mill before batching. During batching, major feed ingredients are conveyed to a hopper above the mixer and weighed using a batch scale in a batching bin. Minor ingredients, such as supplemental lysine and vitamin and mineral premixes, are generally added separately just before mixing. After batching, the ingredients are dropped into a mixer (typically horizontal ribbon mixer) and mixed for about 1½–2 minutes. When mixing has been completed, the feed mixture is reground, also through a No. 6 screen in a hammer mill, and then conveyed into hoppers above the extrusion-cooker.

Extrusion Cooking — Extrusion cooking (Figure 8) is a process involving the cooking and plasticizing of the

Figure 6. Catfish feed mill located in the Mississippi Delta.

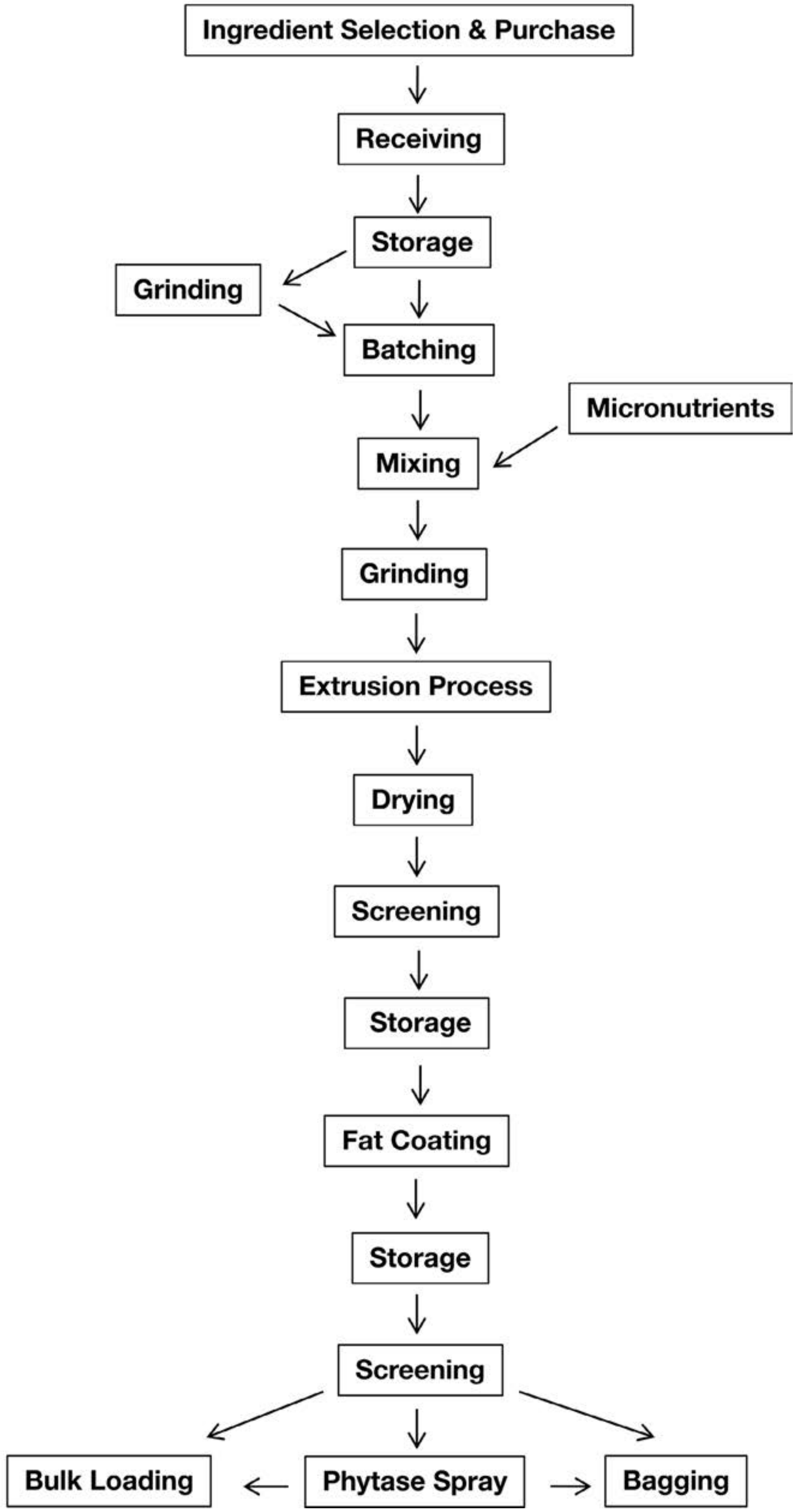

Figure 7. Typical flow scheme for catfish feed processing.

Figure 8. Extrusion cooker.

feed mixture by a combination of heat, pressure, and friction. The mixture is first preconditioned in a conditioning chamber or cooker for 30–45 seconds during which steam or hot water is added to increase the moisture level of the mash to about 25%. Inside the chamber, temperature ranges 250–275 °F. After preconditioning, the mash is continuously transferred into the extruder, where it is exposed to additional steam from injection ports along the length of the barrel. Temperatures in the extruder generally range from 170 to 225 °F and moisture about 24%. The high temperature and pressure conditions are generated from injected steam and friction created by the shearing and kneading actions provided by its flight and kneading elements of the rotating screw through the extruder barrel. The superheated mixture is then forced through a perforated plate or die located at the end of the extruder barrel, and immediately cut at the outer surface of the die by a rotating knife to the desired length. The holes in the die are about 1/8–3/16 inch in diameter, depending on pellet size desired. As the feed comes through the holes of the die into the reduced atmospheric pressure, it instantaneously expands, creating air pockets essential for the feed pellet to float in the water. A minimum of 20–25% starch is typically required for proper gelatinization and expansion when manufacturing floating catfish feeds.

Drying — The warm and moist feed pellets are transferred by a pneumatic conveyor to a multistage dryer (Figure 9). The pellets are spread evenly on the top level of a moving metal belt housed in a large metal chamber with heated air circulating in an upward direction. After moving along the length of the upper dryer belt, the partially dried feed drops to the next lower-level belt and continues moving in the opposite direction. The dyer may have two to three levels, depending on the capacity. The last portion of the lowest level is used to cool the pellets to about 20 °F above the ambient temperature. Catfish feeds are dried at 220–280 °F for about 45 minutes to a moisture content of about 8–10%.

Screening, Fat Coating, Storage, and Delivery — The dried feed pellets are screened using a No. 6 screen to remove fines or dust, which is reclaimed and used as a feed ingredient. Then the pellets are passed through a fat coater to apply a thin layer of fat to the pellet surface to help reduce fines during feed handling. After fat coating, the product is then stored in bins awaiting load out.

Figure 9. Multistage dryer.

Just before loadout, feeds are screened again to remove fines and sprayed with phytase (if used). Most commercial catfish feeds are delivered to the farm in bulk (up to 22 tons) by trucks.

Quality Assurance and Control — Stringent and continuous quality assurance and control measures are essential to consistently produce high-quality feeds. To be effective, these measures must be the responsibility of all those involved from top management down and should encompass all aspects of the feed production process. Ingredients should be thoroughly inspected and sampled for chemical analysis. Since chemical tests lag ingredient use, if specifications are not met, a deficiency claim can be filed with the supplier. In addition, ingredient inventories are maintained, which provides information on the sources and amount used over a certain period. This can be useful in checking and correcting errors in the production process. All equipment should be continually inspected and maintained at proper specifications. Since a uniform mix is essential, feed samples should periodically be analyzed for a known marker, such as a vitamin or a trace mineral. The finished feed should be routinely analyzed for moisture, protein, fat, and fiber, and periodically for micronutrients to ensure they are at the required levels. Each batch of feed should be checked for physical characteristics including floatability, fines, and pellet size. All animal feed mills are regulated under the Food and Drug Administration (FDA) Food Safety Modernization Act (FSMA), and catfish feed mills are certified or in the process to be certified for Best Aquaculture Practices (BAP), which ensure the finished feed is of high quality and safety, and traceable.

Feeding

Feeding is perhaps the most important task in catfish production. Catfish are not fed *ad libitum* (i.e., feed is not continually available). Also, there are no standard feeding practices across the catfish industry. Rather, the person feeding decides how much feed to offer. Thus, feeding is a highly subjective process made even more difficult because fish feeding behavior can vary significantly among ponds. Observing fish behavior during feeding is an important tool in determining the general condition of the fish and the pond environment. If there is an issue, such as the fish not feeding or acting erratically, the person feeding should take the appropriate action to resolve the problem.

Fry

Newly hatched catfish fry (about ¼ inch in total length) are usually held in indoor troughs and tanks for no more than 10 days. Feeding is not necessary during the first 3–5 days posthatch since the fry use their yolk sacs for energy and nutrients. Once the yolk is used up, fry begin to swim freely and seek food. At this stage, the fry are referred to as "swim-up" and can be directly released into nursery ponds. But, if held in the hatchery, salmon or trout starter feeds (50% protein and high in fish meal) are typically used. Hatchery-held fry should be fed at a daily rate equal to about 25% body weight. This is usually done by using automatic feed dispensers.

Before stocking fry, nursery ponds should be properly fertilized to ensure adequate natural foods are available. These include large zooplankton (mainly cladocerans and copepods), insect larvae, and small insects. Newly stocked fry can get most of their nutrient needs from natural foods, at least during the first 2 weeks. To ensure the fry have enough food, they are usually fed twice daily using a finely ground feed powder or "dust" (Figure 10) at about 20 pounds per acre per day. The feed dust should be scattered over as a large area as possible. Fry feed serves as a secondary food source and as a fertilizer

Figure 10. Catfish feeds of various sizes.

Table 9. Examples of feed formulations for catfish fingerlings (percent as fed).		
Ingredient	**35% protein**	**32% protein**
Soybean meal, dehulled, solvent (47%[1])	44.7	39.6
Cottonseed meal, prepress solvent (41%)	15	10
Porcine meat and bone meal[2] (52%)	8	8
Corn grain	20	20
Wheat middlings	9.9	20
Dicalcium phosphate[3]	0.2	0.2
Vitamin premix[4]	0.1	0.1
Trace mineral premix[4]	0.1	0.1
Animal fat/oil[5]	2	2

[1] See footnote 2 in Table 1.
[2] Can be replaced by poultry by-product meal on an equal protein basis depending on cost.
[3] Can be replaced by monocalcium phosphate on an equal available phosphorus basis or microbial phytase at 500 units/kg (sprayed on finished feed).
[4] Meet or exceed all requirements for catfish listed in Table 1.
[5] Sprayed on feed pellets to reduce feed dust ("fines").

to keep the pond fertile. It is not necessary to feed a high-protein feed as is used in the hatchery. Fines from the manufacture of fingerling and food fish feeds are suitable for catfish fry during this phase. After about 3–4 weeks, the fry will have grown into small fingerlings and will come to the pond surface seeking food.

Fingerlings

Once small fingerlings can be seen coming to the water surface, they are fed a 35% protein, floating pelleted feed (containing animal protein) referred to as "mini-pellets" about 1/8-inch diameter (Figure 10). As fish grow, they may be switched to a larger diameter feed pellet referred to as "shortcut" (about 5/32 inch in diameter) containing 35% or 32% protein (Table 9). Research shows protein levels can be reduced from 35% to 32% in catfish fingerlings of 2 inches and above without affecting fish growth. Towards the end of the growing season, fingerlings can be fed a 28% protein food fish feed. Fingerlings are fed once or twice daily to apparent satiation, and twice-daily feeding increases growth.

Food Fish

During grow out, catfish are usually stocked as advanced fingerlings of about 6 inches and larger (≥ 60 pounds per 1,000). They are generally fed a floating feed about 3/16 inch in diameter containing 28% or 32% protein (Figure 10, Table 10) throughout the season.

Feeding Rate — Several factors dictate how much to feed catfish in a production pond. These include standing crop (number and weight of fish present in the pond), fish size, water temperature, water quality, and weather conditions. Generally, fish should be fed daily as much as they will eat (apparent satiation) without wasting feed and without adversely affecting water quality. Feeding to apparent satiation is especially important when catfish are raised in a multiple-batch cropping system (several sizes of fish are present in the pond) because it provides a better opportunity for the smaller, less aggressive fish to feed. The same is true for fish fed less than daily. However, feeding to satiation is challenging since it is difficult to determine when the fish are satiated. Thus, it is easy to overfeed resulting in wasted feed increasing production cost and causing deleterious effects on water quality. As a rule of thumb, feeding rates should not exceed what can be assimilated by all organisms in the pond. Long-term average daily feeding rates should not exceed about 120 pounds per acre for regular production ponds, 200 pounds per acre for intensively aerated ponds, and 250 pounds per acre for split ponds.

Feeding Time — The best time to feed on a large farm is mainly dictated by the logistics required to feed large numbers of ponds in a limited time. As a result, during warm weather, many catfish producers start feeding early in the morning as soon as dissolved oxygen begins to increase. However, in cool weather (late fall, winter, and early spring), water temperature is usually higher in the afternoon, and fish eat better when fed in the afternoon. There appears to be no advantage to feeding at a certain time of the day during the growing season. For example, there were no differences in weight gain, feed consumption, and feed efficiency of catfish raised in ponds and fed to satiation at 8:30 a.m., 4 p.m., and 8 p.m. No differences in emergency aeration time were noted among different feeding times. However, we do not recommend feeding near dark or at night because

Table 10. Examples of feed formulations for catfish food fish grow out (percent as fed).										
Ingredient	**Dietary protein**									
	28%	**28%**	**28%**	**28%**	**28%**	**32%**	**32%**	**32%**	**32%**	**32%**
Soybean meal, dehulled, solvent (47%[1])	35.60	38.80	26.90	21.30	20.20	42.90	45.00	34.90	30.10	32.20
Cottonseed meal, prepress solvent (41%)	7.50	10.00	15.00	20.00	20.00	10.00	15.00	20.00	25.00	20.00
Distillers dried grains with solubles[2], corn (29%)	—	—	—	—	15.00	—	—	—	—	15.00
Porcine meat and bone meal[3] (52%)	5.00	—	—	—	—	5.00	—	—	—	—
Corn gluten feed[4]	—	—	20.00	25.00	—	—	—	20.00	25.00	—
Corn grain	32.25	28.30	15.69	15.00	17.09	20.00	20.00	15.00	17.47	15.00
Wheat middlings	17.50	20.00	20.00	16.31	25.00	20.15	17.20	7.71	—	15.24
Lysine-HCl	—	—	0.31	0.44	0.41	—	—	0.29	0.43	0.31
Dicalcium phosphate[5]	0.45	1.20	0.40	0.25	0.60	0.25	1.10	0.40	0.30	0.55
Vitamin premix[6]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Trace mineral premix[6]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Animal fat/oil[7]	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50

[1] See footnote 2 in Table 1.
[2] Yellow pigments should be monitored, and total dietary lutein + zeaxanthin level should not exceed 7 ppm.
[3] Can be replaced by poultry by-product meal on an equal protein basis depending on cost.
[4] Can be replaced by corn germ meal on an equal protein basis depending on cost.
[5] Can be replaced by monocalcium phosphate on equal available phosphorus basis or microbial phytase at 500 units/kg (sprayed on finished feed).
[6] Meet or exceed all requirements for catfish listed in Table 1.
[7] Sprayed on finished feed pellets to reduce feed dust ("fines").

maximum oxygen demand generally occurs about 6–12 hours after feeding.

Feed Distribution and Feeding Duration — On large commercial catfish farms, feed is typically blown onto the water surface using mechanical feeders pulled by tractors. Since most commercial ponds are relatively large (about 10 acres), the feed must be blown over a large area to make the feed accessible to as many fish as possible. It is better to feed on all sides of the pond, but this is usually not possible because of the prevailing wind. Therefore, feed must be distributed along the upwind side to prevent it from washing ashore. The length of time feed is offered to fish in an individual pond is subjective and generally influenced by logistics. However, the more time spent feeding each pond the better the chance to optimize feeding.

Feeding Once vs. Twice Daily — Generally, feeding once daily to apparent satiation is satisfactory for food fish grow out. It has been shown that feeding twice daily is not necessarily beneficial, at least for fish raised in a single-batch system. The increased amount of feed fed in fish fed twice daily did not result in increased production. More feed is likely wasted by feeding twice daily.

Feeding Once Daily vs. Every Other Day — Although we recommend catfish food fish be fed once daily, feeding less frequently may be appropriate under certain circumstances. It has been shown catfish fed every other day can consume 27–58% more feed on days fed compared with those fed once daily to apparent satiation. Though there are advantages to feeding every other day, we generally do not recommend this practice. This is primarily because fish fed every other day cannot consume enough feed on days fed to compensate for the missed feed on days when they are not fed. Also, feeding every other day extends the production cycle. Feeding every other day may be acceptable as a short-term strategy when economic conditions justify it, but it does not appear to be a sound practice in the long term.

Maintenance Feeding — By definition, maintenance feeding means all feed eaten by the fish is used to maintain the body with no gain or loss of weight. In practice, this is difficult to achieve. It can be approximated by feeding fish a maintenance ration daily or feeding to apparent satiation less than daily. Since fish of various sizes are typically present in a pond at the same time, it is better to feed all they will eat on days fed rather than feeding a little every day. Feeding the fish to satiation will allow the smaller, less aggressive fish to feed. Maintenance feeding may be suitable to maintain market-size fish that cannot be harvested in time. Catfish fed once a week to satiation for relatively short periods during the growing season generally maintain their body weight. Over time, fish may gain weight. For example, after 2 months of feeding hybrid catfish once weekly, a 7% increase in weight gain was observed. At the end of 4 months, the gain was 29%.

Winter Feeding

Catfish do not feed consistently when the water temperature drops below 70 °F. When temperatures fall to 50 °F and below, catfish more or less stop eating. Some catfish producers choose not to feed during winter months, but winter feeding can be beneficial. The magnitude of this benefit depends on the severity of the winter. Fish gain (if fed) or lose (if not fed) more weight during a mild winter than a cold one. There is no standard across the industry on how often and how much to feed fish during the winter. The following winter (November to March) feeding schedule, based on early afternoon water temperatures, is generally recommended:

< 55 °F: Do not feed.
55–65 °F: Feed to satiation 1–2 times per week.
65–75 °F: Feed to satiation 2–3 times per week.

Other Feed and Feedng-Related Matters

Feed Conversion Ratio

"Feed conversion ratio" is a production term used to measure how efficiently an animal converts feed to body mass. It is calculated as pounds of feed fed per pound of weight gain. The lower the value, the better the feed efficiency. In commercial catfish production, feed conversion can markedly impact profitability. For example, at a feed price of $350 per ton, it costs 35 cents of feed to produce 1 pound of fish if feed conversion is 2, while it costs 44 cents at a feed conversion of 2.5. Catfish grown from fingerlings to market size in small research ponds routinely exhibit a feed conversion ratio of 1.8 or lower. While this ratio may be achievable on an individual commercial farm, averaged over the catfish industry, the farm-level feed conversion ratio (feed fed divided by fish sold, not accounting for the weight of fish stocked) is significantly higher. The recent 5-year industry average is about 2.6. This is the result of several factors including mortalities caused by disease or poor water quality, presence of large fish caused by delayed harvest or infrequent harvest in multiple-batch systems, and overfeeding. Theoretically, the best biological feed conversion ratio should occur when animals are fed to satiation or near satiation (Figure 11). However, this is not necessarily true for pond-raised catfish. If the fish are not fed carefully, satiation feeding may lead to poorer feed conversion because it is easier to overfeed when attempting to satiate the fish.

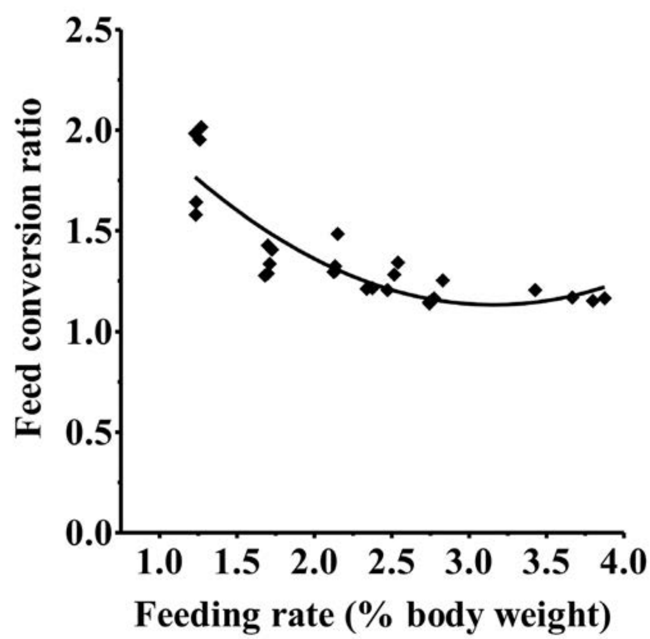

Figure 11. Relationship of feeding rate (percent body weight) and catfish feed conversion ratio.

Processing Yield

Processing yield, an important economic issue for catfish processors, varies during the production cycle, peaking in the fall and markedly dropping in the spring. This appears to be associated with feeding, in that fish are well fed in the fall (high yield) and coming out of the winter into the spring they have not been fed for several months or have been fed sparingly (low yield). When fish are well fed, the DE/DP ratio of the feed can affect yield. As dietary protein decreases the DE/DP ratio increases, thus catfish will deposit more fat in the body cavity as well as in the muscle tissue. This results in reduced carcass and fillet yield. It has been shown that both carcass and fillet yield inversely correlate to visceral fat. To achieve maximum processing yield, high protein (36–40%) feeds would need to be used, but this is typically not economical. Although feeding a 28% protein feed generally results in about 0.5 percentage unit reduction in yield as compared to a 32% protein feed, it is usually still more economical to feed the lower protein feed. Feeding rate and frequency can also have a marked impact on catfish processing yield. Feeding daily to apparent satiation results in maximum processing yield.

Restricted feeding daily or feeding every other day reduces processing yield by reducing muscle growth. Long-term maintenance feeding can severely reduce processing yield.

Hybrid Catfish vs. Channel Catfish

Hybrid catfish (female channel catfish × male blue catfish) have been cultured in the Southern United States for more than 50 years. They eat more aggressively, grow faster, are more resistant to certain diseases, and have a higher survival rate than channel catfish. Advances in breeding technologies have made large numbers of hybrid catfish available. Hybrids currently account for about 70% of total catfish production in the United States. They appear to have similar nutrient requirements as channel catfish. Hybrids are aggressive eaters and tend to accumulate more visceral fat than channel catfish, especially larger fish. Hybrids can quickly become too large and decrease in value if they are not harvested on a timely basis, or if some fish remain in the pond after harvest.

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