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# COMPOSITION AND FORMULATION OF CHANNEL CATFISH FEEDS

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# Composition and Formulation of Channel Catfish Feeds

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## Introduction

Some farmed animals meet their nutritional needs by eating natural food items or forages grown specifically for consumption, some may require a supplemental feed in addition to what they may consume naturally, and some may derive a part of their nutrient needs through microbial synthesis in the intestine. But some animals, including catfish, are fed a nutritionally complete diet that provides all known nutrients at required levels along with the energy necessary for their utilization. With catfish, this diet is needed because the contribution of nutrients from food items in pond water is assumed to be relatively small in comparison with total nutrient requirements. Also, nutrients produced in the catfish intestine are considered to be of little consequence. In this bulletin, we examine the nutritional composition of catfish feeds, as well as the feedstuffs that are used to produce it. Further, we discuss how information on nutrient requirements and feedstuffs can be used to formulate diets for catfish using least-cost computer programs. Finally, the bulletin presents a brief section on trends and recommendations regarding catfish.

## Feed Composition

In the broadest classification, a feed is made up of moisture (water) and dry matter (Figure 1). Dry matter can be further divided into organic matter and ash. Organic matter includes crude protein, vitamins, carbohydrates (crude fiber and soluble carbohydrates), and fats and oils. Ash is made up of the mineral portion of the feed.

### Moisture

Moisture is actually a nutrient, but it is often not thought of in that regard. It is found in all feedstuffs and can be utilized by animals. This form of water is not as important to fish, since they live in water, or to livestock that have free access to water as it is to animals without a constant source of water. The only concern with moisture in catfish feeds is to ensure that the level does not exceed about 12% to prevent the feed from molding. Commercial catfish feeds typically contain 9–10% moisture.

### Dry Matter

About 90% of a catfish feed is dry matter, which is composed primarily of organic compounds ($\geq$ 95%) and a small percentage of ash ($\leq$ 5%). The organic portion supplies energy and nutrients aside from essential minerals, which are present in the ash.

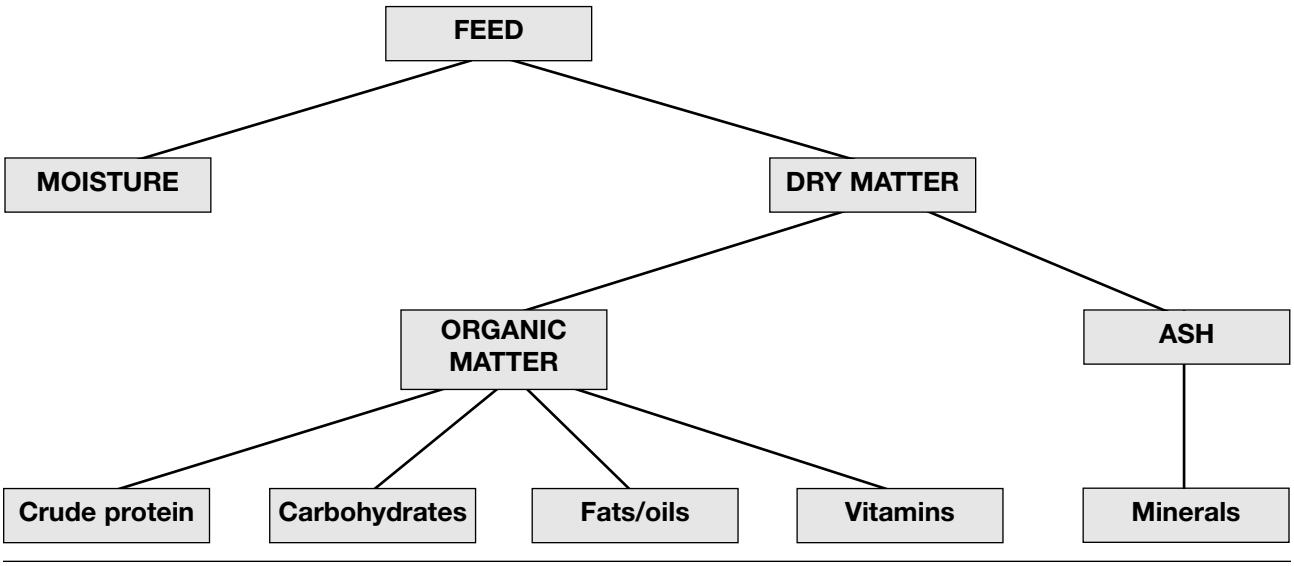


**Figure 1. Catfish feed composition.**

# ENERGY

All animals require energy for growth, reproduction, and health, whether they live on land or in water or they are cold-blooded or warm-blooded. While their dietary requirements, sources, and efficiency of utilization of energy may differ, their energy needs are ultimately met from energy that is released during the metabolism of carbohydrates, fats and oils, and protein (amino acids). Quantitatively, energy is the most important component of the diet because feed intake in animals that have free access to feed is largely regulated by dietary energy concentration. Therefore, feeding standards for many animals are based on energy needs. Because catfish typically do not have free access to feed, feed intake may be more a function of feed allowance than of the dietary energy concentration, except perhaps 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 protein is important, primarily because a deficiency of nonprotein energy in the diet will result in the more expensive protein being utilized for energy. Also, if dietary energy is excessively high, food intake may decline, resulting in a reduced intake of essential nutrients. Or if too much energy is consumed, dressed yield and shelf life of frozen products may be reduced because of an increase in visceral and tissue fat.

One of the most notable differences in fish nutrition compared with other livestock concerns energy requirements. For example, fish require less energy for protein synthesis. 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 spatial 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. 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 digestible energy to crude protein (DE/P), range from 7.4–12 kcal per gram. Based on current knowledge, a DE/P ratio of 8.5–9.5 kcal per gram appears to be optimum for use in commercial catfish feeds.

Because fish evolved in an aqueous environment where food items typically contained high levels of protein and fat and little carbohydrate, they utilize protein and fats more efficiently for energy than carbohydrates. However, herbivorous and omnivorous fish

typically utilize carbohydrate for energy fairly well. For example, the channel catfish's digestibility coefficient for carbohydrate in cooked corn averaged 70%; in purified cornstarch, 66%. The fact that catfish can utilize carbohydrate relatively well is fortunate not only because it is an inexpensive source of energy, but also because starch is necessary to make a floating feed. Also, fats and oils, which are the most concentrated and most highly digestible sources of energy for catfish, must be used sparingly because high concentrations can be detrimental to fish growth and product quality. Therefore, the predominant energy source in commercial catfish feeds is from carbohydrates contained in grains (primarily corn) and grain milling by-products.

# NUTRIENTS

### Protein and Amino Acids

Animals require a continual supply of protein throughout life for maintenance and growth. Actually, they do not have a requirement for protein as such, but rather require amino acids that compose proteins and nitrogen for synthesis of other nitrogenous compounds. Yet, we still refer to a "protein requirement" when describing the nutrient needs of catfish. This is because the most economical method of providing amino acids and nitrogen in the quantity and quality needed is to feed a mixture of protein feedstuffs in the diet in the proper amounts and proportions. Ingested proteins are broken down to release amino acids that may be used for synthesis of tissue proteins or, if in excess, utilized for energy. Feeding excess protein is undesirable because it is expensive and also adds the physiological burden of excreting the extra nitrogen, which also negatively impacts water quality. Thus, catfish feeds should be balanced in regard to protein and energy with ample energy supplied from nonprotein sources (i.e., starch and fat).

Nutritionally, amino acids may be classified either as indispensable (must be supplied in the diet) or as dispensable (can be synthesized by the animal and not required in diet). Most simple-stomach animals, including catfish, require the same 10 indispensable amino acids. It is critical that all of the 10 indispensable amino acids are provided in the proper amounts and proportions. If a single indispensable amino acid is missing, growth will not occur. In practice, an amino acid will not be completely missing, but if a specific feed mix is improperly balanced, the concentration of one or more indispensable amino acids could be lower than required by the animal. A deficiency of a single amino acid will decrease growth. That is, the animal will grow only to the point that the supply of the deficient amino acid is exhausted. The deficient amino acid that limits growth is referred to as the "limiting" amino acid in that specific feed mix. Using the feedstuffs typically found in catfish feeds, lysine is considered the first limiting amino acid. Generally, if catfish feeds are formulated from commonly used feedstuffs to meet the dietary lysine requirement, all other indispensable amino acids are present in adequate amounts. Amino acid requirements are best met by feeding a mixture of feedstuffs because different proteins contain amino acids in varying amounts and proportions. Supplemental amino acids may be used to correct an imbalance if necessary. In practice, lysine is typically the only supplemental amino acid needed in commercial catfish feeds.

The optimum level of dietary protein to include in commercial catfish diets is dependent on several factors, but using high-quality feedstuffs containing as little as 24% protein provides for fast growth and high feed efficiency. However, there may be a problem in using low-protein feeds for catfish because dietary energy levels are too high relative to the protein levels. As protein is decreased, the ratio of dietary energy to protein increases, resulting in increased fattiness in the fish. Even though dietary protein can be reduced to 24% without negatively affecting weight gain and feed efficiency, feeds containing less than 28% protein generally result in increased fattiness, which may lead to a reduction in dressed yield. Over the last 20 years or so, we have conducted numerous studies that included comparisons of 28% and 32% feeds prepared from various feedstuffs, and there have been absolutely no differences in weight gain or feed efficiency. In some of the studies, we observed a slight increase in body fat and a decrease in dressed yield in fish fed a 28% protein feed compared with 32% protein feed. On average, from different studies we conducted so far, fish fed a 28% protein diet had about 0.5% lower carcass and fillet yield. Based on these studies and studies conducted at other research facilities, we recommend using a 28% protein feed with protein supplied primarily from high-quality oilseed meals. If

feed is severely restricted, a higher protein feed may be beneficial, but with typical feeding rates that allow a daily feed allowance of around 100 pounds per acre, there is no need for high-protein feeds.

## Carbohydrates

Carbohydrates belong to a group of compounds that includes sugars, starches, celluloses, and other closely related substances that are among the most abundant organic compounds found in nature. They are the primary form of energy stored in seeds, roots, and tubers, making up 60–70% of the dry weight of most grains. For catfish and other simple-stomached animals, carbohydrates can be broadly divided into an indigestible fraction (fiber) and a digestible fraction (sugars and starches). Ability to utilize sugars and starches as an energy source differs among fish species. Most fresh- and warmwater fish, including catfish, can utilize higher levels of dietary starch more efficiently than marine and coldwater fish. This may be attributed to the fact that warmwater fish have a much higher intestinal concentration of the enzyme (amylase) necessary for utilization of starch than coldwater species. Catfish digestibility values for carbohydrates in cooked corn range from 62–78%.

There is actually no dietary carbohydrate requirement for catfish because, like other animals, they are capable of synthesizing carbohydrates from lipids and proteins. Even so, catfish feeds inherently contain fairly large amounts of grain or grain by-products that are rich in starch. Starch is important in catfish feeds because it is an inexpensive energy source that can help prevent the more expensive protein from being used for energy. Catfish readily use protein for energy if other nonprotein energy sources are not included in the diet. Starch is also important in feed manufacturing. It binds ingredients and allows for the expansion of extruded feed pellets, making them water-stable and able to float on the water surface. A typical catfish feed contains 35–40% or more digestible carbohydrates, plus an additional 3−7% crude fiber. Dietary fiber should be maintained at as low a level as practical to minimize the amount of indigestible material passing into the culture water via the feces.

## Lipids

Lipids (fats and oils) are a highly digestible source of concentrated energy. For example, fish oil contains more than twice the energy found in an equivalent amount of carbohydrates and is 97% digestible to catfish. In addition to supplying energy, lipids are a source of essential fatty acids (EFA) that cannot be synthesized by the animal and thus must be provided in the diet. Essential fatty acids are classified based on their chemical structures and are designated as either n-3 (omega-3) or n-6 (omega-6) fatty acids. Although there may be exceptions, fish generally appear to require n-3 fatty acids. The EFA requirements of catfish appear to be met by 0.5–0.75% of highly unsaturated n-3 fatty acids, which can be supplied by marine fish oil such as menhaden oil. Natural food organisms found in the pond may also be a good source of EFA, but their contribution to the EFA requirement has not been quantified. However, we do know that the high concentration of highly unsaturated n-3 fatty acids found in zooplankton exceeds the EFA requirements of small catfish fingerlings that prey on these natural food organisms. Lipids also serve as a vehicle for absorption of fat-soluble vitamins and are precursors for steroid hormones and other compounds. They may also increase feed palatability, affect the flavor of edible tissue, and help maintain neutral buoyancy of fish.

Since catfish appear to have the ability to synthesize most of their fatty acids, nutritionally there may be no “best” level of dietary lipid except that needed to provide EFA. But since lipid is a concentrated source of energy that can spare protein, additional lipid should be included in catfish diets. However, too much dietary lipid may result in excessive fat deposition in the body cavity and tissues. This problem may adversely affect processing yield, product quality, and storage of processed products. Also, weight gain and feed efficiency are depressed when catfish are fed diets containing 15% or more lipids. Dietary lipid is not an issue in practice, because 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 lipids aids in the reduction of feed dust (“fines”). Both animal fats and fish and vegetable oils have been used in commercial catfish feeds. The type of lipid used is largely dependent on price and availability. When economical, a mixture of menhaden oil and catfish oil is used.

## 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. If catfish are fed purified diets under controlled laboratory conditions, characteristic vitamin

deficiency signs can be induced when the diet is deficient in a particular vitamin. However, vitamin deficiencies are rarely encountered in natural populations of fish or in cultured catfish. This is because vitamins are present in natural food sources, and some vitamins can be synthesized in the intestine. In the case of cultured fish, many vitamins are inherent in feedstuffs used in commercial fish feeds. In addition, a vitamin supplement is added. It should be emphasized that, although microorganisms in the intestine of certain animals can synthesize some vitamins in quantities sufficient to meet metabolic needs, the microflora of the catfish intestine is limited and likely does not contribute significantly to the vitamin needs of catfish. Further, vitamins present in feedstuffs have usually been disregarded during feed formulation because the bioavailability of most vitamins to catfish is not known. In addition, although natural food (zooplankton) collected from commercial catfish ponds contains vitamins (some in relatively high concentrations), their contribution to the vitamin nutrition of catfish has not been fully quantified. However, we have conducted several studies with catfish that indicate that vitamins inherent in feedstuffs and/or in natural foods contribute significantly to the vitamin nutrition of catfish.

Qualitative and quantitative vitamin requirements for catfish have been fairly well defined. Initially, vitamin requirements for catfish were typically determined with small, rapidly growing fish under laboratory conditions. These values were considered to be sufficient to meet the needs of pond-raised fish. But vitamin requirements are affected by numerous factors, including stresses encountered in the culture environment. Therefore, we conducted several studies on the grow-out of catfish in earthen ponds where the fish were fed a commercial-type diet with and without supplemental vitamins or with and without specific vitamins to provide some insight into practical vitamin requirements. Results indicate that the concentrations of certain vitamins can be reduced and some vitamins can be removed from the vitamin premix without affecting fish performance. Vitamin supplements should provide essential vitamins in sufficient quantities to meet the requirement and to compensate for losses due to feed processing and storage. A supplement should contain adequate vitamins to provide the following concentrations in the final feed: A, 1,000 IU per pound; D3, 500 IU per pound; E, 30 parts per million (ppm); K, 4.4 ppm; thiamin (B1), 2.5 ppm; riboflavin (B2), 6 ppm; pyridoxine (B6), 5 ppm; pantothenic acid (B5), 15 ppm; folic acid (B9), 2.2 ppm; B12, 0.01 ppm; and ascorbic acid (C), 50 ppm. Choline, nicotinic acid (B3), and biotin (B7) are required, but a typical catfish feed contains adequate amounts without a supplement.

## Minerals

Fourteen minerals are essential to catfish for normal metabolism and skeletal structure, as well as to maintain an osmotic balance between body fluids and their environment. The requirement for most minerals is met by those present in feedstuffs or from mineral supplements added to the feed. In addition, catfish can absorb certain minerals from the water. For example, a calcium supplement is not necessary when the culture water contains adequate calcium. However, catfish require 0.45% calcium in the diet when raised in calcium-free water. In practice, a calcium supplement is not needed because most pond water contains ample calcium, and commercial catfish feeds generally contain a relatively high level of calcium from feedstuffs. In most animal feeds, the dietary ratio of calcium to phosphorus is an important consideration, but this ratio does not appear to be critical for catfish, apparently because calcium is regulated at the gills. Other minerals for which a supplement is not needed include sodium, potassium, chloride, magnesium, and sulfur. These minerals are either absorbed from culture water, or they are abundant in feedstuffs typically used in catfish feeds.

As with calcium, catfish require a relatively high amount of phosphorus (0.35%). However, catfish do not obtain significant amounts of phosphorus from the water. Furthermore, catfish feeds are composed primarily of feedstuffs of plant origin, some of which contain high levels of phosphorus, but only about one-third of the plant phosphorus is utilizable by catfish. Most phosphorus in plant feedstuffs is in a bound form as phytate, and catfish do not have the enzyme (phytase) necessary to utilize this form of phosphorus. Fish meal or animal by-products contain high levels of phosphorus, about 50–70% of which is utilizable by catfish. However, commercial catfish feeds typically contain low levels of these feedstuffs. Thus, catfish feeds are typically supplemented with dicalcium or defluorinated phosphates to ensure that adequate amounts of phosphorus are available. An alternative to phosphorus supplements is commercially available phytase that releases the phytate-bound phosphorus and makes it available to catfish. Research has shown that phytase enzymes are effective, and phytase has been successfully used in some commercial catfish feeds for several years. One advantage of using phytase enzymes

is that they significantly reduce fecal phosphorus. The recommended rate is 500 phytase units per kilogram of feed in a feed that contains at least 0.6% total phosphorus from feedstuffs. In addition to a phosphorus supplement, catfish feeds are supplemented with a trace mineral premix that provides minerals that are required in small quantities. The premix should contain ample minerals to provide the following concentration of minerals in the final feed: cobalt, 0.05 ppm; iodine, 2.4 ppm; zinc, 200 ppm; selenium, 0.1 ppm; manganese, 25 ppm; iron, 30 ppm; and copper, 5 ppm.

# FEEDSTUFFS

No single feedstuff can supply all of the nutrients and energy required for optimum catfish growth. Therefore, commercial catfish feeds are composed of a mixture of feedstuffs and vitamin and mineral premixes that provide adequate amounts of essential nutrients and the energy necessary for their utilization. The amount of each feedstuff used depends on several factors, including nutrient and energy content, ingredient cost, availability, and processing characteristics. Although feedstuffs contain protein and other nutrients and energy, they are usually classified as either protein or energy feedstuffs. Those containing 20% or more protein are classified as protein feedstuffs, and those containing less than 20% protein are classified as energy feedstuffs. Protein feedstuffs are further divided by source, either animal or plant. Although there are exceptions, animal proteins are generally considered to be of higher quality than plant proteins, primarily because they typically contain a superior complement of indispensable amino acids and are more digestible. There are numerous feedstuffs that may be nutritionally suitable for use in catfish feeds, but in reality relatively few are readily available on a timely basis and at reasonable cost.

## Animal Protein Feedstuffs

Animal proteins come from inedible tissues from marine sources and meatpacking or rendering plants. Those that have been used in catfish feeds include fish meal, meat and bone meal, blood meal, meat and bone/blood meal blend, catfish offal meal, and poultry by-product meal. Even though animal proteins are generally an excellent source of protein for catfish, they do not appear to be a necessary dietary component for catfish after they reach a size of 6–7 inches. Fish meal can be completely replaced in food fish feeds by meat and bone meal or meat and bone/blood meal blends, all of which can be replaced by a mixture of properly balanced plant feedstuffs.

**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 quality that 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 has been used at levels up to 50–60% in catfish fry feeds, up to 15% in catfish fingerling feeds, and from 0–12% in food-fish grow-out feeds. Currently, because of its high cost, little if any fish meal is used in commercial catfish feeds except for starter 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, or 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 15–20%. Meals prepared from beef products are not recommended because of issues associated with "mad cow" disease.

**Meat and Bone/Blood Meal Blend —** Blended products are available for use in catfish feeds that are mixtures of meat and bone meal and blood meal. The two feedstuffs are mixed to give the desired nutritional characteristics, and the blend may mimic the nutritional profile of menhaden fish meal (at least in regard to lysine) and provides 60–65% protein. The blended products are an excellent protein source for use in catfish feeds and are generally used as a replacement for fish meal. Only blends containing porcine meal and blood are recommended.

**Poultry By-Product Meal —** Poultry by-product meal is made up of ground, rendered, or clean parts of slaughtered poultry carcasses. It contains heads, feet, underdeveloped eggs, and visceral organs but does not

contain feathers. The product contains approximately 58–65% protein and is an excellent product for use in catfish feeds. Its use in catfish feeds is limited because it is not available on a regular basis at a reasonable cost per unit of protein.

**Catfish Offal Meal —** Catfish offal meal is prepared from catfish processing waste and contains about 58% protein of relatively good quality. It is highly palatable to catfish. It is rarely used in part because there is not enough quantity to supply the industry, and there is also some concern related to recycling catfish products through catfish.

## Plant Protein Feedstuffs

The primary plant protein sources used in catfish feeds are soybean meal and cottonseed meal. Other oilseed meals, such as canola meal, peanut meal, and sunflower meal, could be used but are generally not available at a reasonable cost in the primary catfish growing areas. Aside from soybean meal, other plant proteins are generally deficient in lysine. However, supplementation of these meals with lysine makes them nutritionally acceptable for use in catfish feeds. Other protein sources used in catfish feeds include distillers' dried grains with solubles. Some plant proteins contain toxins and antinutritional factors, but these are typically not a problem because they are either present in very low concentrations or are inactivated during processing of the meal or during feed manufacturing.

**Soybean Meal —** Dehulled, solvent-extracted soybean meal is prepared by grinding the flakes after removal of the oil from dehulled soybeans by solvent extraction. It contains 48% protein and is the predominant protein source in catfish feeds. Soybean meal 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. In recent years, its use has been curtailed somewhat because of increasing cost.

**Cottonseed Meal —** Solvent-extracted cottonseed meal is obtained by grinding the cake remaining after the oil has been 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 cyclopropenoic acids that can be toxic; however, levels of these chemicals in commonly available cottonseed meal are generally well below levels toxic to catfish. Cottonseed meal has generally been used in catfish feeds at a level of 10–15%, but levels up to 30–35% can be used when the feed is supplemented with lysine. Cottonseed meal can replace about half the soybean meal in catfish feeds.

**Distillers' Dried Grains with Solubles —** Distillers' dried grains with solubles (DDGS) are the primary residues, after removal of the alcohol by distillation, from the yeast fermentation of cereal grains. The most common product in the United States is DDGS from corn. 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. Distillers' grains contain a relatively high level of yellow pigments. This limits the amount that can be used in catfish feeds because of the resulting discoloration that occurs and makes the product unacceptable to the typical consumer.

## Energy Feedstuffs

Energy feedstuffs contain less than 20% crude protein. Those used in commercial catfish feeds are primarily grain and grain by-products, including corn grain, corn gluten feed, corn germ meal, wheat grain, wheat middlings, and rice bran.

**Corn Grain —** Corn grain has been used traditionally as a main energy source in catfish feeds. Corn improves expansion of feed pellets during extrusion resulting in a pellet that floats. Because of recent dramatic increases in its price, levels of corn in catfish feeds have decreased. A minimum of 15–20% corn is typically included in the feed to ensure proper expansion and floatability of feed pellets. Cooking during the extrusion process improves energy digestibility of corn for catfish. The digestible energy value of corn grain for catfish is about 1,150 kcal per pound for catfish.

**Wheat Grain —** Wheat is a good source of energy for catfish but is generally more expensive than corn. As a result, 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 grain or other grains in catfish feeds and are routinely used at levels up to about 25−30% of the feed. 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 with hulls or broken rice at levels typical 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%. Higher levels could be used if the rice bran is defatted. Rice bran has a digestible energy value of about 970 kcal per pound for catfish.

**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 to produce starch, syrup, and oil. It is a potential energy source for catfish feeds. This product typically contains about 18–20% crude protein (depending on protein level, it could be classed as a protein source) and 10% fiber, and 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. 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 pigment problem in catfish product.

**Corn Germ Meal —** Corn germ meal consists of corn germ with other parts of the corn kernel from which most of the oil has been removed. It is the product obtained in manufacture of corn meal, corn grits, hominy feed, and other corn products. The corn germ meal presently used in the catfish industry contains 18−21% protein (depending on protein level, it could be classified as a protein source). It is low in yellow pigments and thus can be used in catfish feeds at levels up to about 35% of the feed to replace part of other protein feedstuffs and/or part of the corn grain.

**Animal and Plant Fats and Oils —** Animal and plant fats and oils are highly concentrated sources of energy as well as a source of essential fatty acids. Animal fats used in catfish feeds include catfish offal oil, poultry fat, and menhaden fish oil. Plant oils can be used but are generally too expensive. 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.

# Feed Formulation

The goal of formulating feeds using least-cost computer programs is not just to formulate the cheapest feed but rather to make the least expensive feed possible given a specific set of criteria that ensure the feed is of the quality needed for the target animal. The goal is to develop a properly balanced feed that meets the nutritional and energy requirements of an animal in a palatable and digestible form. To formulate least-cost feeds, information is needed on ingredient availability, price, and nutrient and nonnutrient content. Feed producers also need an understanding of nutrient variability among batches and sources of ingredients, as well as the limits to the amount of a specific ingredient that can be used. In addition, producers must know the nutrient requirements of the animal and how the animal digests and assimilates nutrients and energy from ingredients. Any specific nonnutritional restrictions that may apply must also be considered. For example, production of a floating feed requires that an adequate amount of starch must be included in the formula.

Although computer programs handle the mathematical computations necessary for least-cost formulation, the formulator provides the criteria used for those calculations. This requirement means the results are only as reliable as the input information. Therefore, these programs are generally used by nutritionists who have the knowledge and experience to properly integrate the various pieces of information to ensure a reliable result. In practice, the formulator sets specifications for ingredients, the level of inclusion, the price, and the nutrient requirements that must be met for a specific formulation. Specifications can be set to include an exact, a minimum, or a maximum amount for an ingredient or nutrient. There are several specifications that need to be considered (Table 1). However, if too many specifications are set, the program may not be capable of calculating a formula, or it will result in a formula that is not practical. In reality, a catfish feed formula only needs specifications for protein, lysine, and phosphorus. If common feed ingredients are used, and if the lysine requirement is met, the requirements for other amino acids and energy are met as well. In addition, vitamin and trace mineral premixes are added to ensure that the requirements for these nutrients are met. Regardless of the specifications set, it is essential to check the formula to ensure that the ingredient composition is practical and that the nutritional requirements are met. Once a basic formula is established,

typically only minor adjustments are needed to get a practical formula that meets the set criteria.

Given current ingredient costs and using the specifications given in Tables 1 and 2, the result would likely be similar to Formula 1 (Table 3). Note that animal protein was not included in Formula 1 because of high cost. If animal protein is desired, the specifications can be changed and the formula rerun to ensure that animal protein is included. For example, setting a minimum of 5% for porcine meal will result in a formula similar to Formula 2 (Table 3).

**Table 1. Ingredient specifications for a least-cost catfish feed.**

| Ingredient | Specification | Amount | Unit |
|---|---|---|---|
| Soybean meal (48%[1]) | Maximum | 50.0 | % |
| Cottonseed meal (41%) | Maximum | 20.0 | % |
| Corn grain[2] | Minimum | 15.0 | % |
| Corn gluten feed or germ meal[3] | Maximum | 35.0 | % |
| Distillers' grains with solubles[4] | Maximum | 20.0 | % |
| Rice bran | Maximum | 15.0 | % |
| Menhaden fish meal (61%) | Maximum | 15.0 | % |
| Porcine meal (52%) | Maximum | 15.0 | % |
| Poultry byproduct meal (58%) | Maximum | 15.0 | % |
| Supplemental fat | Minimum | 1.5 | % |
| | Maximum | 3.0 | % |
| Phytase enzymes | Minimum | 230.0 | FTU[5]/lb |
| | Maximum | 230.0 | FTU/lb |
| Dicalcium phosphate | Maximum | 2.0 | % |
| Vitamin premix | Include | | |
| Trace mineral premix | Include | | |

[1] Number represents percentage protein.
[2] Some corn needed for feed manufacture.
[3] Use depends on price. Corn germ meal contains a lower level of yellow pigments.
[4] Yellow pigment levels can vary greatly among different sources and dietary yellow pigments should be monitored if distillers' grains with solubles are used.
[5] FTU = phytase unit.

**Table 2. Nutrient specifications for 28% protein least-cost catfish feed.**

| Nutrient | Specification | Amount | Unit |
|---|---|---|---|
| Crude protein | Minimum | 28.00 | % |
| | Maximum | 28.00 | % |
| Crude fiber | Maximum | 7.00 | % |
| Total fat | Maximum | 6.00 | % |
| Available phosphorus | Minimum | 0.30 | % |
| Available phosphorus | Maximum | 0.40 | % |
| Digestible energy | Minimum | 2.60 | kcal/g |
| Digestible energy | Maximum | 2.80 | kcal/g |
| Available lysine[1] | Minimum | 1.43 | % |
| Available methionine | Minimum | 0.26 | % |
| Available methionine + cystine[2] | Minimum | 0.65 | % |
| Xanthophylls | Maximum | 7.00 | ppm |

[1] Lysine should be 5.1% of the dietary protein.
[2] Total sulfur amino acids should be 2.3% of the dietary protein.

**Table 3. Examples of 28% protein least-cost catfish food-fish formulas using specifications given in Tables 1 and 2.**

| Ingredient (%) | Formula 1 | Formula 2 |
|---|---|---|
| Soybean meal (48%[1]) | 21.4 | 17.4 |
| Cottonseed meal (41%) | 20.0 | 20.0 |
| Porcine meal (41%) | — | 5.0 |
| Corn grain | 15.0 | 15.0 |
| Corn gluten feed | 20.0 | 20.0 |
| Wheat middlings | 5.4 | 9.8 |
| Distillers' dried grains with solubles | 16.1 | 10.7 |
| Fat/oil[2] | 1.5 | 1.5 |
| Lysine HCl | 0.4 | 0.4 |
| Phytase enzymes[3] | include | include |
| Catfish vitamin premix[4] | include | include |
| Catfish trace mineral premix[4] | include | include |

[1] Values represent percentage protein.
[2] Sprayed on top of feed.
[3] Provide 230 FTUs phytase per pound of feed. Phytase reduces fecal phosphorus. Dicalcium phosphate can be used if phytase is not available.
[4] Premix meets dietary requirements.

# Trends and Recommendations

The knowledge base that has been developed for catfish nutrition is extensive and gives the industry some options in regard to diet formulation that were not available a few years ago. This knowledge coupled with increasingly tight (and sometimes nonexistent) profit margins has led to the necessity of reducing production cost by decreasing the cost of the catfish diet. The most expensive component of the diet is protein. Protein cost has increased dramatically during the last few years primarily due to the soaring costs of fish meal, soybean meal, and grains used in making catfish feeds. Therefore, the trend has been to use less expensive feedstuffs and to reduce the amount of dietary protein. In this regard, catfish diets tend to be based primarily on plant proteins. If animal protein is used, less expensive animal protein feedstuffs are recommended. Specifically, the more expensive animal protein feedstuffs, such as fish meal, are replaced with poultry by-product meal or porcine meal. Alternatively, all animal protein is sometimes replaced with a combination of soybean meal and cottonseed meal. In addition to these trends, soybean meal and corn are being replaced by less expensive feedstuffs. Research data indicate that at least half of the soybean meal can be replaced by cottonseed meal or a combination of cottonseed meal and corn gluten feed, corn germ meal, or distillers' dried grains with solubles. Additionally, the amount of corn grain used has also been reduced considerably. In regard to the amount of dietary protein needed, a soybean-based diet containing 24% protein can be used without affecting weight gain and feed conversion for fish fed at typical feeding rates. However, under current conditions where alternative feedstuffs are used to replace a large portion of soybean meal, we recommend that catfish diets used for grow-out contain 28% protein with or without an animal protein supplement. The 28%-protein diet provides a margin of safety, and it will not result in accumulation of excessive body fat as lower protein diets do.


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