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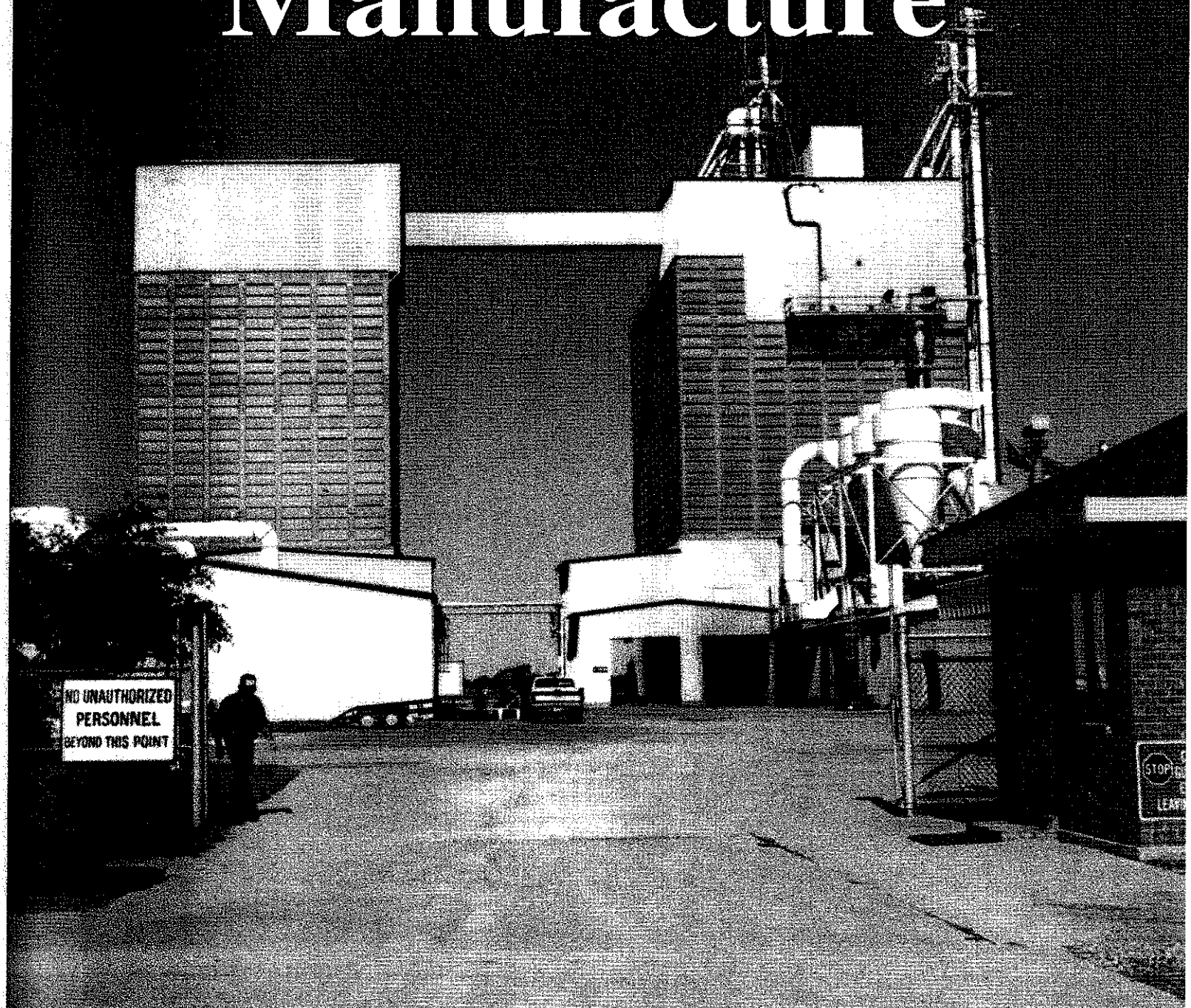
Catfish Feed Manufacture



MAFES
MISSISSIPPI AGRICULTURAL & FORESTRY EXPERIMENT STATION Vernon G. Hurt, Director Mississippi State, MS 39762
Donald W. Zacharias, President Mississippi State University R. Rodney Foil, Vice President

Catfish Feed Manufacture

Meng H. Li
Research Assistant
Delta Branch Experiment Station

Edwin H. Robinson
Fishery Biologist
Delta Branch Experiment Station

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Preface

This report provides information on factors to consider during the manufacturing of catfish feeds and describes the processes used to manufacture catfish feeds. Some of the constraints faced in manufacturing catfish feeds are also discussed as well as methods used to ensure that feeds of high quality are continually produced. Reference citations, which detract from readability, have been omitted. Nutritional information was taken from various review articles and the description of feed manufacturing is based on the authors' experience as well as conversations with various people involved in the manufacture of catfish feeds. This information is presented in a manner that will be usable to those interested in catfish feeds and their manufacture.

Acknowledgments

The authors appreciate the support of the Mississippi Agricultural and Forestry Experiment Station and the Delta Research and Extension Center for funding for this bulletin. Special thanks to those who provided critical reviews of the manuscript.

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Introduction

Feed manufacturing involves the processing of mixtures of feedstuffs and feed additives into a usable form. There are several goals and considerations in feed manufacturing, some of which are nutritional and some of which are nonnutritional. Typically, the primary goal is to increase profits of animal production by maximizing the nutritional value of a feedstuff or a mixture of feedstuffs. Depending on the animal species, this process may range from a simple reduction of particle size to forming feed pellets through steam pelleting or extrusion.

Catfish feeds are unique compared to feeds used for terrestrial animals grown for food because catfish feeds must be pelleted, water stable, and generally made to float on the water surface. Thus, most commercial catfish feeds are manufactured by extrusion. If a particular feed additive will not withstand the rigors of extrusion, the feed may be manufactured by steam pelleting into a sinking pellet.

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

This bulletin is intended to provide information on catfish feed manufacture that may be useful to students, scientists, nutritionists, and catfish producers. It covers nutritional and nonnutritional factors that must be considered in manufacturing catfish feeds as well as feed manufacturing practices, feed types, and quality control.

Nutritional Considerations

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

Nutrient Requirements

Nutrient requirements for catfish, particularly small catfish, have been fairly well defined (Table 1). In formulating and manufacturing catfish feeds, it is essential that the finished feed meet the requirements given in Table 1 and be manufactured in a form that is readily consumed and is digestible. Feed processing may have a profound effect on certain nutrients and little effect on others. It may make certain

Table 1. Nutrient requirements of young channel catfish for optimum growth.

Nutrients	Requirements
Protein (%)	25-36
Digestible energy (kcal/g dietary protein)	8-9
Essential amino acids (% of protein)	
Arginine	4.3
Histidine	1.5
Isoleucine	2.6
Leucine	3.5
Lysine	5.1
Methionine + cystine	2.3
Phenylalanine + tyrosine	5.0
Threonine	2.0
Tryptophan	0.5
Valine	3.0
Vitamins	
A (IU/lb)	450-900
D_3 (IU/lb)	110-220
E (IU/lb)	23
K	R[a]
Thiamin (ppm)	1.0
Riboflavin (ppm)	9.0
Pyrodoxine (ppm)	3.0
Pantothenic acid (ppm)	14
Biotin	R
Folic acid (ppm)	1.0
B_{12}	R
Niacin (ppm)	14
Choline (ppm)	400
Inositol	NR[b]
C (ppm)	60
Minerals	
Calcium (%)	0.10
Phosphorus (%)	0.45
Magnesium (%)	0.04
Sodium	ND[c]
Potassium	NR
Chloride	ND
Sulfur	ND
Iron (ppm)	20
Zinc (ppm)	20
Copper (ppm)	4.80
Manganese (ppm)	2.40
Selenium (ppm)	0.25

[a]R=required
[b]NR=not required
[c]ND=not determined

nutrients more available and others less available. However, the feed manufacturing process should produce a feed pellet of good quality with the least amount of detrimental effects on nutrient availability.

Feed ingredients

Commercial catfish feeds are comprised of a mixture of feedstuffs and vitamin and mineral premixes that provide adequate amounts of essential nutrients as well as the energy necessary for their utilization. The amount of each feed ingredient used depends on several factors including nutrient requirements, cost, availability, and processing characteristics. The effects of feedstuffs on feed manufacturing are discussed under the section "nonnutritional considerations."

Protein supplements

Feedstuffs containing 20% crude protein or more are considered protein supplements. Protein supplements may be classified as animal and plant proteins.

Animal proteins used in animal feeds come from inedible tissues from meat packing or rendering plants, milk products, and marine sources. Those typically used in catfish feeds include fishmeal, meat and bonemeal, and blood meal. Animal proteins are generally considered to be of higher quality than plant proteins, primarily because of their superior complement of indispensable amino acids. Animal protein is essential in the diet of fry and small fingerling catfish.

Fishmeal prepared from whole fish appears to be a better protein supplement than other animal proteins. However, fishmeal does not appear to be essential in the diet of catfish after they reach a size of 6-7 inches. Fishmeal can be completely replaced by meat and bonemeal or meat and bone/blood meal in diets for growout catfish. There is also evidence that animal proteins can be completely replaced by plant proteins in catfish growout feeds without affecting growth and feed efficiency.

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

Fishmeal. Fishmeal is prepared from dried, ground tissues of undecomposed whole marine fish or fish cuttings such as menhaden, herring, or whitefish. Fishmeal contains 60% to 80% protein of excellent quality that is highly palatable to catfish. Since fishmeal is a good source of essential amino acids, it is often used to supplement feeds containing plant proteins. Fishmeal is also rich in energy, minerals, and essential fatty acids. It is used at levels up to 50% in catfish fry feeds, up to 12% in catfish fingerling feeds, and from 0 to 8% in catfish growout feeds.

Meat and bonemeal. Meat and bonemeal 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 bonemeal contains approximately 50% crude protein. Its protein quality is inferior to whole fishmeal because it contains less lysine, and because the consistency of the product may vary considerably. It is good source of minerals. Its high ash content may limit its use because of possible mineral imbalance. The maximum level recommended for catfish feeds is 15%.

Blood meal. Blood meal is prepared from clean, fresh animal blood, excluding hair, stomach belchings, and urine, except in trace quantities that are unavoidable. It contains 80% to 86% crude protein and is an excellent source of lysine. It is deficient in methionine. The levels should not exceed 5%.

Meat and bone/blood meal blend. Special products are available for use in catfish feeds that are mixture of meat and bonemeal and blood meal. The two feedstuffs are mixed to give the desired nutritional characteristics. Generally, the blend mimics the nutritional profile of menhaden fishmeal and provides 60-65% protein. Blended products are an excellent protein source for use in catfish feeds and are generally used to replace fishmeal.

Catfish offal meal. Catfish offal meal is prepared from catfish processing waste, primarily heads, frames, and visceral organs. The product contains approximately 50% protein. It is of better nutritional quality than meat and bonemeal, but not as good as menhaden fishmeal. It is highly palatable to catfish; however, it is seldom used in catfish feeds because it is not available in adequate amounts throughout the growing season.

Poultry byproduct meal. Poultry byproduct meal is made up of ground, rendered or clean parts of the carcass of slaughtered poultry. It contains heads, feet, underdeveloped eggs, and visceral organs, but does not contain feathers. The product contains approximately 59% good quality protein, but it is seldom used in catfish feeds because it is not available on a regular basis at a reasonable cost per unit of protein.

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

Soybean meal, dehulled, solvent-extracted. Dehulled, solvent-extracted soybean meal is prepared by grinding the flakes after removal of the oil from dehulled soybeans by solvent extraction. Dehulled, solvent-extracted soybean meal contains 48% protein and is the predominant protein source used in catfish feeds. It has the best amino acid profile of all common plant protein sources and is highly palatable and digestible to catfish. Antinutritional factors are destroyed or reduced to insignificant levels with heat that is applied during the extraction process. Levels of soybean meal up to 60% have been used in commercial catfish feeds without detrimental effects.

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

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

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

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

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

Canola meal. Canola meal is prepared from a special rapeseed by solvent extraction to remove the oil. Compared to typical rapeseed meal, canola meal is low in glucosinolates and erucic acid, which may be detrimental to fish growth. Canola meal contains about 38% protein, but is relatively low in lysine. It is palatable to catfish and can be used at levels up to about 20-25% without supplemental lysine. It is seldom used in catfish feeds because of lack of availability in catfish growing areas.

Energy supplements

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

Corn grain and corn screenings. Corn and corn screenings are used interchangeably in commercial catfish feeds as relatively inexpensive sources of energy. Corn screenings are obtained in the cleaning of corn and include light and broken corn grain. Cooking improves energy digestibility of corn for catfish. Corn contains a yellow pigment, xanthophyll, which at high levels has been shown to accumulate in catfish, giving the flesh a yellowish coloration that is undesirable to consumers. Corn grain or screenings have been used in catfish feeds up to 45% of the feed without adverse effects. The digestible energy value of corn grain and corn screenings for catfish is about 1,150 kcal/lb.

Wheat grain. Whole wheat grain is ground prior to use. It 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/lb for catfish.

Wheat middlings. Wheat middlings are fine particles of wheat bran, shorts, germ, and flour recovered from milling wheat grain. Depending on cost, wheat middlings are used to replace corn or corn screenings in catfish feed and are routinely used at levels up to about 25% of the feed. Low levels (2-5%) are often used to improve pellet binding. Wheat middlings has a digestible energy value of about 950 kcal/lb for catfish.

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

Animal and plant fats and oils. Animal and plant fats and oils are highly concentrated sources of energy as well as sources of essential fatty acids. Animal fats used in catfish feeds include catfish offal oil, beef tallow, poultry fat, and menhaden fish oil. Tallow is not recommended for use in winter feeds because it is a saturated fat, which may cause problems at cold temperatures. Plant oils can be used, but animal fats are generally preferred because they are normally less expensive.

Currently, catfish offal oil and menhaden oil are the two predominant oils used in commercial catfish feeds. There is evidence that levels of menhaden oil from about 2% or higher may reduce disease resistance in catfish. Often, the two are blended in equal parts or in a ratio of 75% catfish oil to 25% menhaden oil. Supplemental fat is generally sprayed on the finished feed pellets at a rate of 1.5 to 2%, primarily to reduce feed dust ('fines'). Fats and oils have a digestible energy value of around 4,000 to 4,200 kcal/lb for catfish, depending on the particular fat.

Vitamins

Vitamin requirements of catfish have been fairly well studied. Catfish require a dietary source for 14 vitamins for proper metabolic function and normal growth. Most commercial feedstuffs used in catfish feeds contain vitamins, but the amount is often limited and the bioavailability of vitamins from feedstuffs is not known. Thus, commercial catfish feeds are supplemented with a vitamin premix that provides vitamins in quantities necessary to meet dietary requirements including losses due to feed processing. Vitamins commonly added to commercial catfish feeds and the recommended amounts are given in Table 2.

Minerals

Although there have been a limited number of studies on the mineral requirements of catfish, particularly under typical rearing conditions, catfish appear to require the same minerals as other animals. Mineral studies with fish are complicated by the fact that fish can absorb certain minerals from the water. For example, catfish can meet their calcium requirement by absorption from water – if the water contains a sufficient amount of calcium.

In addition to typical needs for minerals, catfish also require minerals for osmotic balance between the body fluid and their environment. If 15% or more

Table 2. The recommended level and commonly used vitamin compounds in catfish feeds supplied by vitamin premixes. Includes overages to account for losses during feed manufacture.

Vitamins	Recommended level	Form
A (IU/lb)	2,000	Vitamin A acetate
D_3 (IU/lb)	1,000	D-activated animal sterol
E (IU/lb)	30	DL-alpha-tocopherol acetate
K (ppm)	4.4	Menadione dimethylpyrimidinol bisulfite
Thiamin (ppm)	11	Thiamin mononitrate
Riboflavin (ppm)	13.2	Riboflavin
Pyrodoxine (ppm)	11	Pyrodoxine-HCl
Pantothenic acid (ppm)	35	Calcium d-pantothenate
Biotin	0	None
Folic acid (ppm)	2.2	Folic acid
B_{12} (ppm)	0.01	Vitamin B_{12}
Niacin (ppm)	88	Niacin
Choline (ppm)[a]	275	Choline
Inositol	0	None
C (ppm)[b]	200	Ethylcellulose or fat-coated ascorbic acid

[a]Supplementation may not be needed because of relative high amounts found in feedstuffs used in a typical catfish feed.

[b]Amount can be lowered if more stable form of ascorbic acid is used. Target from 60 to 90 ppm in final feed.

Table 3. The recommended level and commonly used mineral compounds in catfish feeds supplied by mineral premixes.

Minerals	Recommended level	Form
Phosphorus (%)	0.5	Dicalcium phosphate or defluorinated calcium phosphate
Zinc (ppm)	200	Zinc oxide
Iron (ppm)	30	Ferrous sulfate and/or ferrous carbonate
Manganese (ppm)	25	Manganese oxide
Copper (ppm)	5	Copper sulfate
Iodine (ppm)	2.4	Calcium iodate
Selenium (ppm)[a]	0.1	Sodium selenite
Cobalt (ppm)	0.05	Cobalt carbonate

[a]Maximum allowable by FDA is 0.1 ppm; usually supplied by the vitamin premix.

animal protein is included in catfish feeds, supplemental trace minerals are generally not necessary. Since most growout feeds for catfish generally contain low levels of animal protein, a trace mineral premix is commonly added to commercial catfish feeds (Table 3). In addition, phosphorus is added as dicalcium phosphate or defluorinated calcium phosphate.

Nonnutritional Considerations

Although nutritional considerations are of prime importance, nonnutritional factors often influence the composition of the final product. The logistics of procuring and storing feedstuffs and feed additives are primary nonnutritional considerations. In general, feed ingredients must be available on a consistent basis, be easily handled in the manufacturing process, be able to withstand the rigors of the manufacturing process, and be economical. These characteristics are the primary reason that soybean meal and corn have been the main feedstuffs typically used in catfish feeds.

Peanut meal and cottonseed meal are often priced economically and could be used in catfish feeds, but their use is limited, not only because of nutritional deficiencies, but also because they are not available on a consistent basis during the catfish growing season. In addition, cottonseed meal appears to slow feed production by slowing extrusion when included in the feed at levels exceeding 15 to 20% of feed. Also, cottonseed meal appears to be more abrasive than other commonly used feed ingredients, thus increasing equipment wear.

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

When formulating catfish feeds, the feed manufacturing process must be considered because there is an interrelationship between feed formulation and feed manufacturing. For example, extrusion requires that at least 25% of the feed be composed of grains or grain milling byproducts for proper gelatinization and expansion necessary for good pellet stability and float. This is generally not a problem, but the type and amount of grain or grain milling byproducts that are used may be affected by humidity in the air. Levels of wheat middlings up to 25% can generally be used except at high air humidity where the level may be reduced to 10 to 15% and the amount of corn grain increased to avoid making the feed too sticky and difficult to handle.

As mentioned, cottonseed meal at high levels slows the extrusion process. High-fat feedstuffs, such as rice bran, are generally limited to 5 to 10% of the feed because high levels of fat make the feed more difficult to pellet or extrude, at least with the equipment commonly used to manufacture catfish feeds in the southeastern United States. Supplemental fat is sprayed on the finished catfish feeds to reduce feed dust (fines). Highly fibrous feedstuffs must be limited to rather low levels because high levels of fiber negatively impact pellet quality.

Another consideration during catfish feed manufacture, is that the conditions of high temperature, pressure, and moisture encountered during pelleting and extrusion destroy certain nutrients and improve the availability of others. Vitamins are particularly sensitive to destruction, thus, catfish feeds are normally overfortified with vitamins to account for losses during feed manufacture. Energy digestibility of starches appears to be enhanced by the extrusion process.

Nonnutritive Feed Additives

Nonnutritive feed additives that have been used in animal feeds include hormones, antimicrobial agents,

antioxidants, antifungals, water, flavorings, pellet binders, and fiber. Some of these additives have been used in catfish feeds while others have not been shown to be beneficial.

Certain synthetic hormones have been approved for use by the U.S. Food and Drug Administration (FDA) for use in cattle feed, but hormones have not been approved for use in fish feeds. Sex hormones have been shown to improve growth and feed efficiency in certain fish, but not in catfish.

Other nonhormonal compounds have been evaluated as growth promoting factors in catfish. An agent, Ractopamine™ (Eli Lily and Co., Greenfield, IN), has been reported to improve growth and reduce fat deposition in catfish, but it is not approved for use.

Terramycin™ (Pfizer, Inc., New York, NY) and Romet™ (Hoffmann LaRoche Inc., Nutley, NJ) are antibiotics commonly added to catfish feeds for disease treatment. Additional information on these antibiotics is presented in the section on "feed types."

Antioxidants may be added to catfish feeds; however, vitamin premixes and oils that are used are stabilized with antioxidants, such as ethoxyquin, BHA (butylated hydroxyanisole), and BHT (butylated hydroxytoluene). Also, natural antioxidants, such as vitamins C and E, are found in feed ingredients and vitamin premixes. Thus, supplemental antioxidants are not generally added to catfish feeds. In addition, oxidation is normally not a major problem since catfish feeds are not stored for lengthy periods in the major catfish growing areas of the United States. If used, the maximum allowable levels approved by the FDA are 200 ppm of fat content for BHA and BHT and 150 ppm of feed for ethoxyquin.

Feed ingredients arrive at the feed mill at 12% to 13% moisture and a fairly high level of moisture is added to the feed mash as steam or as water to enhance pelleting or extrusion. Added moisture as well as some of the moisture found in feedstuffs is driven off during drying. Since commercial catfish feeds are dried to around 8 to 10% moisture, and, since they are not generally stored for more than a day or so, antifungal agents are not used routinely.

Catfish readily eat feeds made from a variety of feedstuffs; thus, palatability is rarely a problem, even on all-plant protein feeds. As a result, flavorings, other than those found in natural feedstuffs, are not needed.

Pellet binders are used in steam-pelleted catfish feeds to improve water stability of the finished pellet. Nonnutritive binders, such as lignosulfonates, bentonites, and certain cellulose derivatives, or nutritive binders, such as specially processed milo, may be used. The stability of steam-pelleted feeds in water is dependent on the type and amount of binder used. Typically, these types of feeds are only stable in water for a few minutes, but this is generally ample time for catfish to consume the feed if they are actively feeding.

Fiber, other than that found in feedstuffs, is not added to commercial catfish feeds since it does not appear to be beneficial. In fact, fiber is maintained at a low level in catfish feeds since it is considered indigestible by catfish and may be detrimental to water quality.

Manufacturing Processes

Regardless whether a feed is floating or sinking the general scheme of feed manufacture is the same (Figure 1). Whole grains are ground through a hammermill prior to batching. The feed ingredients are

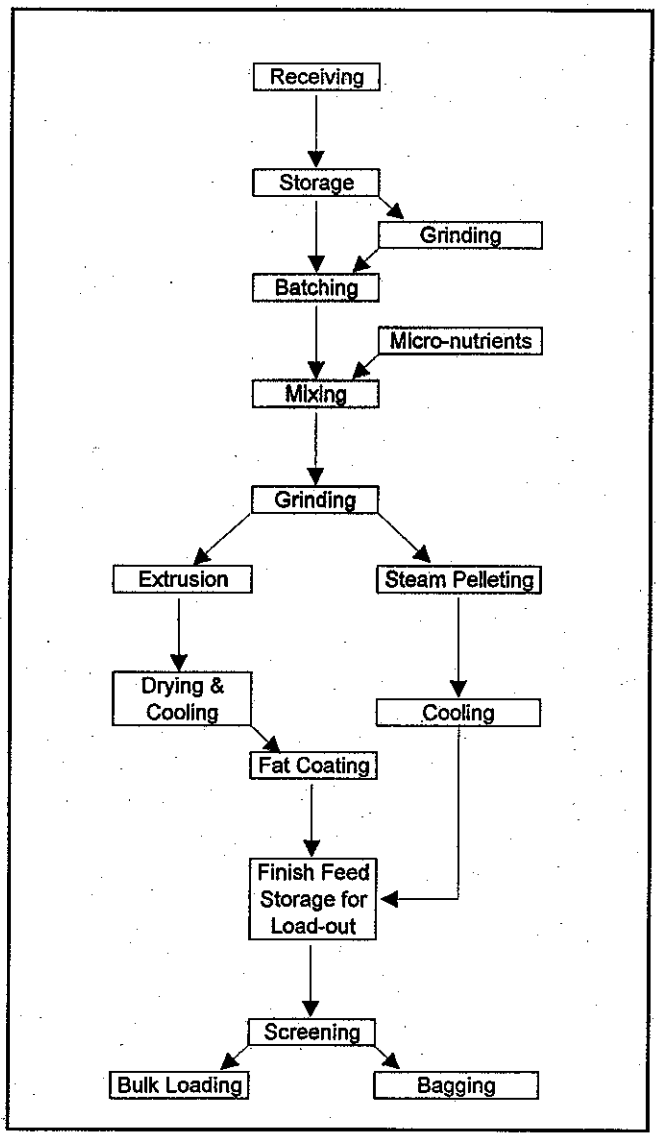

Figure 1. Block diagram of typical scheme for manufacturing catfish feeds.

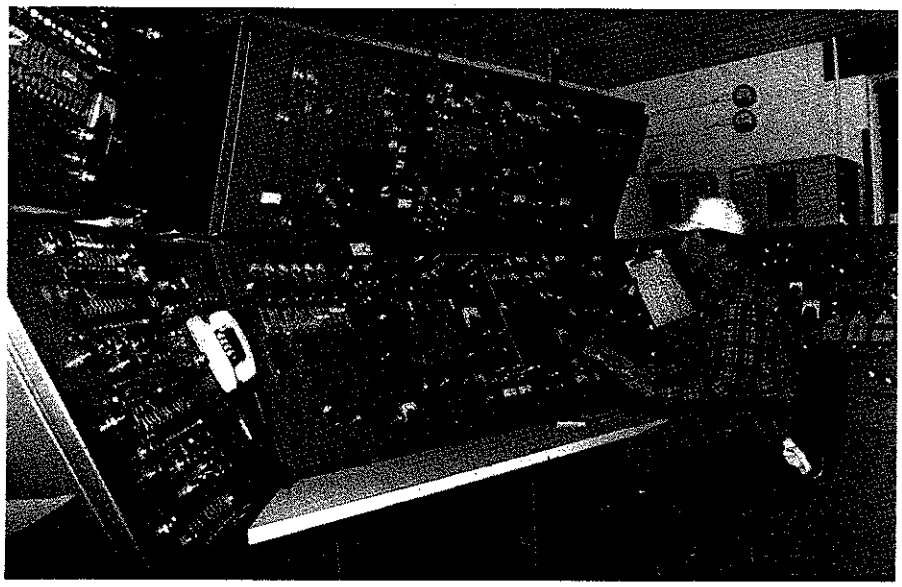

Figure 2. Control center for catfish feed mill.

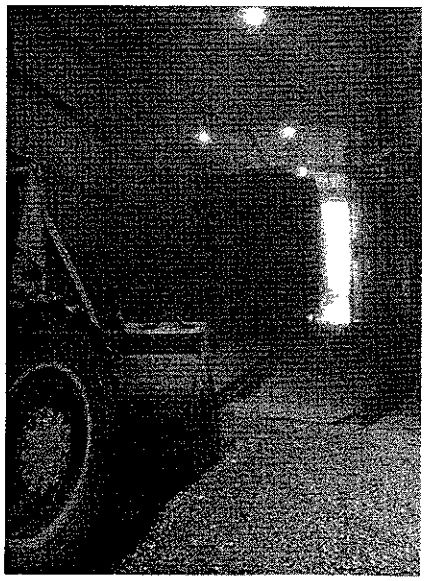

Figure 3. Railroad car unloading feed ingredients.

batched, weighed, mixed, and then reground. After regrinding, mixed feed ingredients are either extruded or steam-pelleted and then cooled or dried, fat-coated, and stored for loadout. During preparation for loadout the feed is screened to remove "fines" and then loaded into trucks for bulk delivery or bagged. Operation of the various phases of feed manufacture are controlled by operators from a control center (Figure 2).

Receiving and storage

Feedstuffs and other ingredients are either received at the mill by rail or by truck. Rail is generally more economical. Feedstuffs are unloaded from the railcars or trucks (Figures 3 and 4) and transferred to storage houses or bins (Figures 5 and 6). As feedstuffs are needed they are moved by conveyers or screws to the appropriate section of the feed mill for processing.

Grinding, batching, and mixing

Whole grains (corn, wheat, etc.) are ground though a number 7 screen (Figure 7) in a hammermill (Figure 8) prior to batching and mixing. During batching, feedstuffs are moved into a hopper above the mixer and weighed prior to mixing (Figure 9). After batching, the batch is dropped into a mixer (Figure 9) and mixed for a predetermined time (usually 1.5 to 3 minutes). After mixing the feed mix is ground through a smaller screen, a number 4 or 6 depending on the type of feed being manufactured. After regrinding, the feed mixture is moved into hoppers above the extruders or the pellet mill.

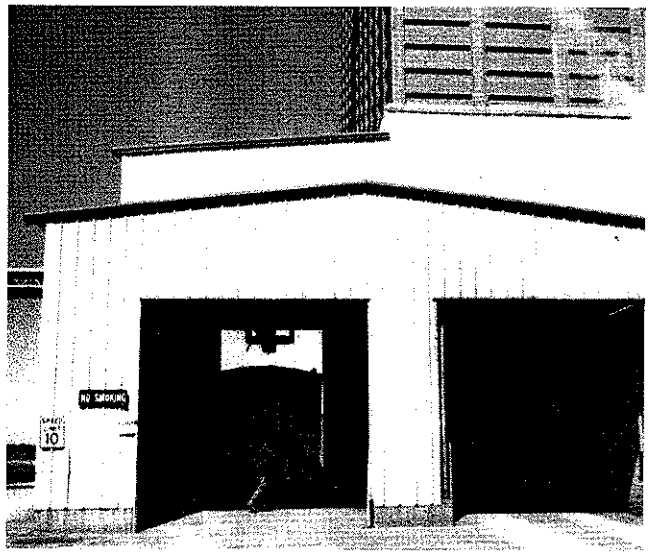

Figure 4. Truck unloading feed ingredients.

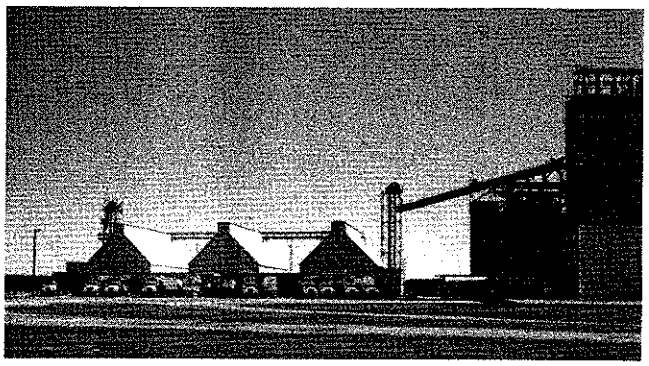

Figure 5. Feed ingredient storage houses.

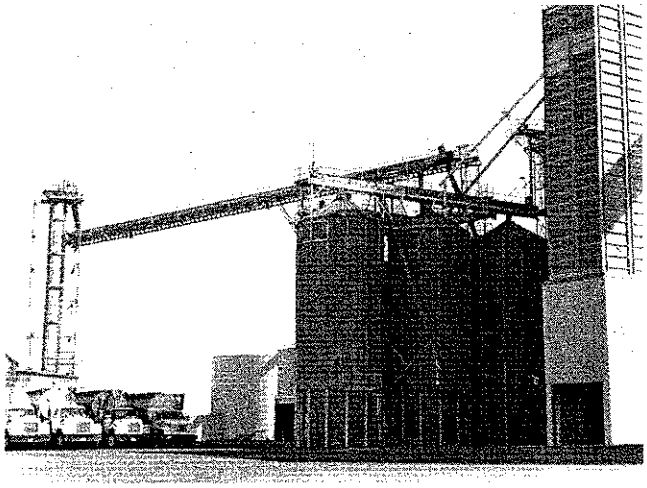

Figure 6. Feed ingredient storage bins.

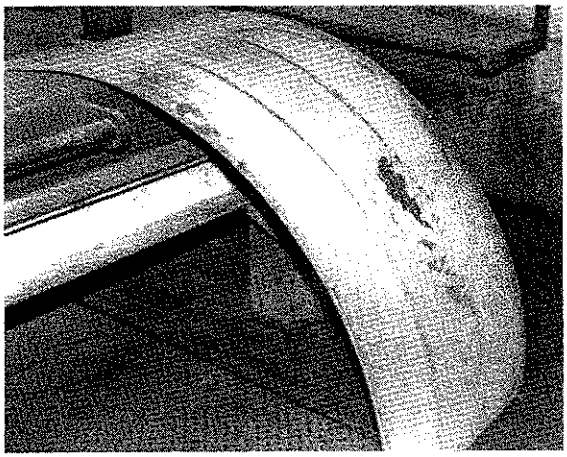

Figure 7. Hammermill screen.

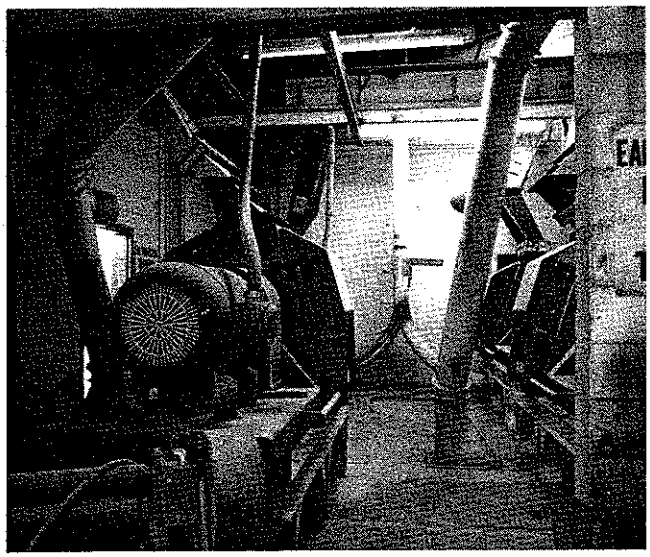

Figure 8. Hammermill.

Steam pelleting

Steam-pelleted (sinking) feeds are manufactured by using moisture, heat, and pressure to form ground feed ingredients into larger homogenous feed particles. Steam is added to the ground feed ingredients to increase the moisture level to 15 to 18% and temperature to 160° to 185° F. Steam helps to gelatinize starches, which bind the feed particles together. The hot "mash" is then forced through a pellet die in a pellet mill (Figure 10). Die size is dependent on the size of pellet desired. The pellets exit the die at about 10% moisture; thus, they require little drying but must be cooled.

Steam-pelleted feeds are generally less expensive to manufacture than extruded feeds because less energy is expended in their manufacture. Also, less destruction of nutrients occurs during steam-pelleting as compared to extrusion. A typical steam-pelleted feed is shown in Figure 11.

Extrusion

Extrusion is a process that involves the plasticizing and cooking of feed ingredients in the extruder barrel by a combination of pressure, heat, and

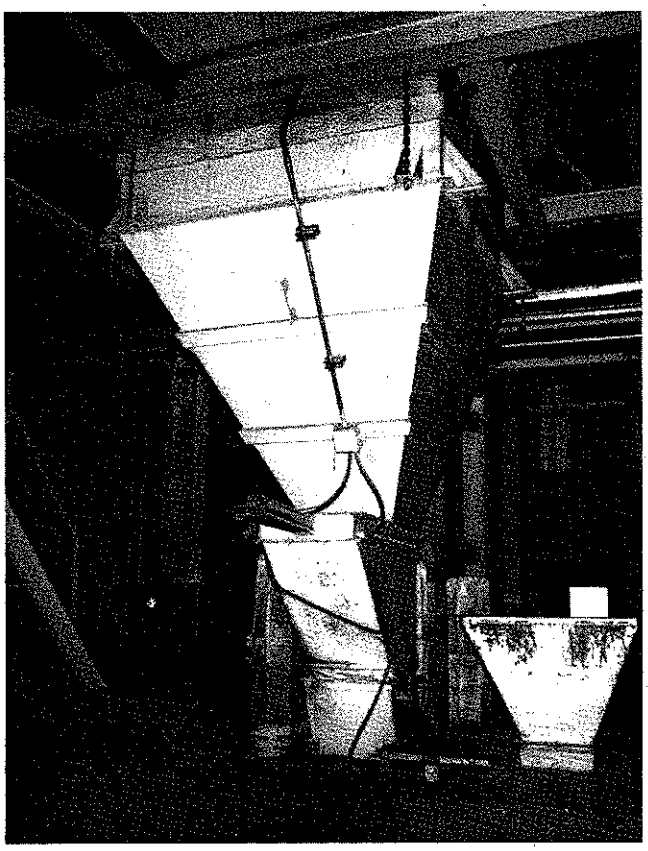

Figure 9. Feed batching system (mixer is directly below the batching system).

friction. Fish feed ingredients are a mixture of starchy and proteinaceous materials that are moistened to form a "mash." The "mash" may be preconditioned in a conditioning chamber (Figure 12) for 3 to 5 minutes during which moisture is added in the form of steam (water can also be injected) to increase the moisture level of the "mash" to about 25%. During this period, the "mash" is cooked as moisture penetrates the feed particles. Preconditioning may improve flavor development and feed digestibility, reduce extruder barrel wear, and allow for increased volume through the extruder.

After preconditioning, the "mash" enters the extruder (Figure 12), which is a jacketed barrel that contains a rotating screw. Temperatures in the extruder generally range from 190° to 300°F and are generated from friction in the extruder.

The superheated mixture is then forced through a die (about 1/8- to 7/32-inch diameter for catfish feeds) located at the end of the extruder barrel (Figure 13). The die restricts product flow, thus causing development of the necessary pressure and shear. The die is also used to shape the product (extrudate) passing through it.

As the product passes through the die, a sudden reduction in pressure results in the vaporization of

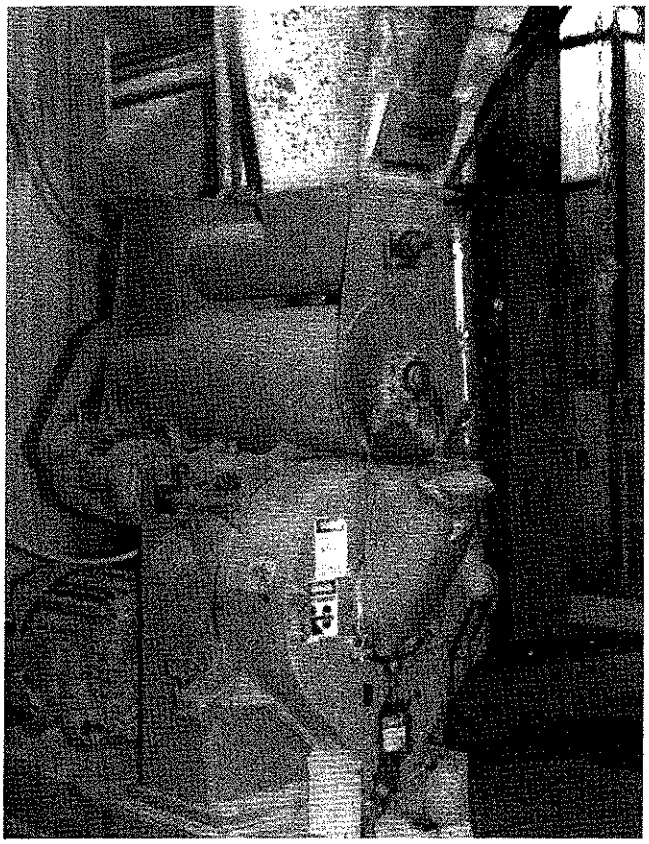

Figure 10. Pellet mill.

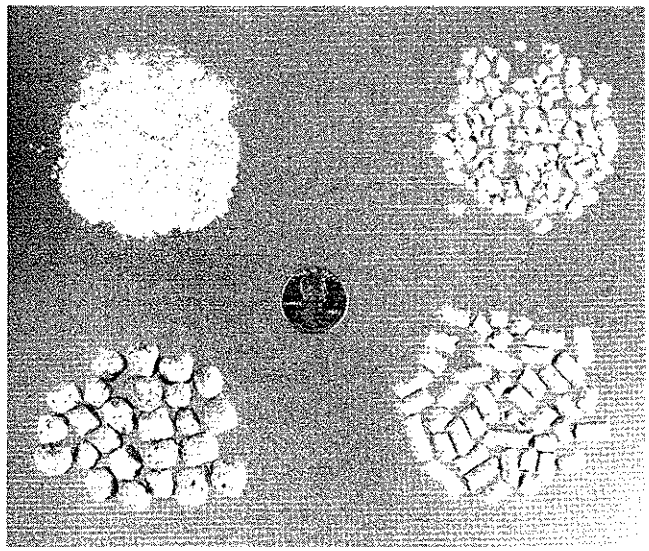

Figure 11. Examples of various feed types: top left, meal-type feed; bottom left, extruded (floating) feed; top right, crumbled feed; bottom right, steam-pelleted (sinking) feed.

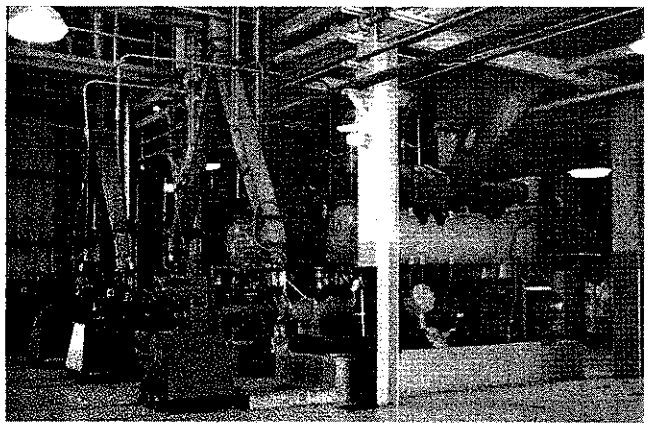

Figure 12. Extruder with conditioning chamber.

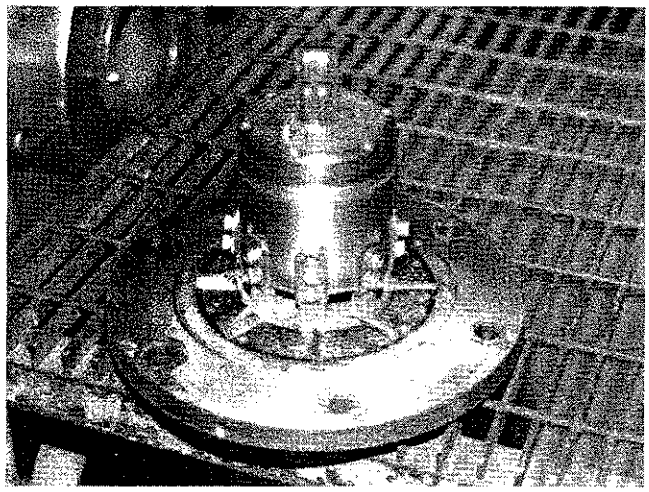

Figure 13. Extruder die with cutting blade.

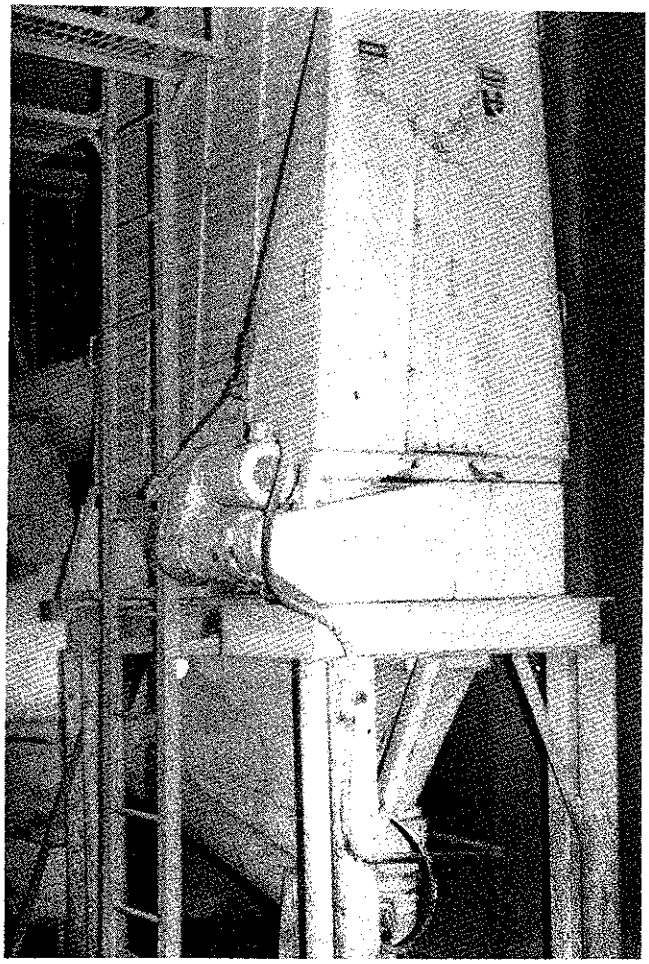

Figure 14. Cooler for cooling steam-pelleted feeds.

part of the water in the mixture and the feed pellets expand. The moisture level of the pellets leaving the extruder is higher (18-21%) than that of steam-pelleted feed; thus, extruded pellets must be dried at high temperatures. A typical extruded catfish feed is shown in Figure 11.

Drying and cooling

Some moisture is lost by flash evaporation as the feed pellet exits the die and by evaporative cooling after the feed pellets are exposed to air. Steam-pelleted feeds exit the die near a moisture level of 10% and require cooling but little drying (Figure 14). Extruded feeds also lose moisture by flash evaporation and evaporative cooling (about 2%), but require additional drying since they contain 20% or so moisture as they enter the dryer. Extruded fish feeds should be dried to a moisture content of 8 to 10%. At this level of moisture, the "shelf life" of the product is extended. Drying is generally accomplished using a multi-stage dryer, which has different temperature zones (Figure 15). For extruded catfish feeds, drying time is around 30 minutes. Temperatures range from 275° to 300°F.

Fat-coating, storage, screening, and delivery

After drying, extruded catfish feeds are normally passed through a fat-coater (Figure 16), which applies a thin layer of fat to the pellet surface. Fat coating helps reduce feed dust (fines). After fat-coating, the product is stored in bins (Figure 17) awaiting loadout.

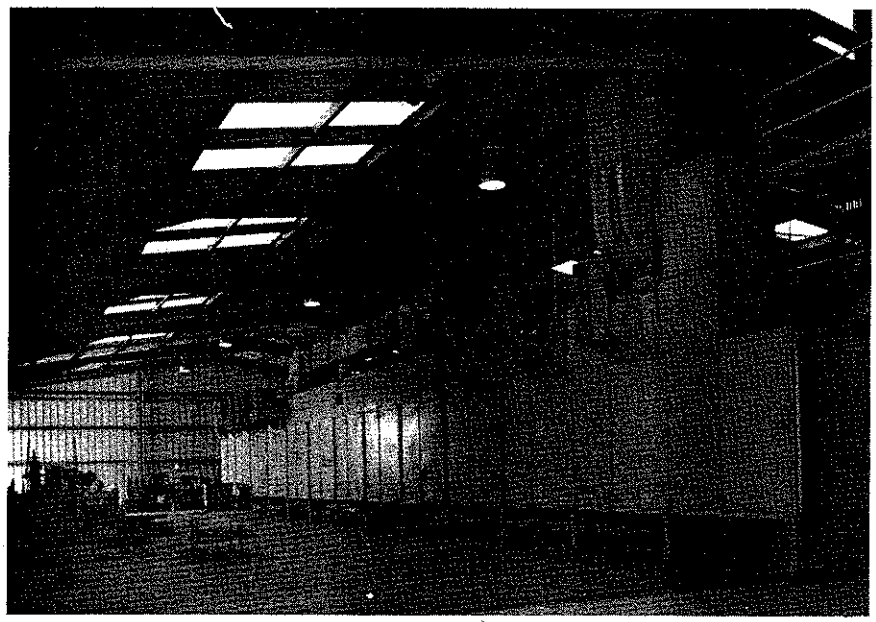

Figure 15. Dryer for drying extruded feeds.

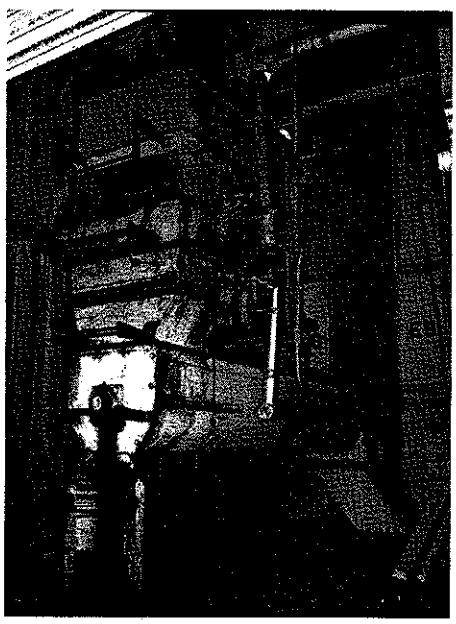

Figure 16. Fat coater.

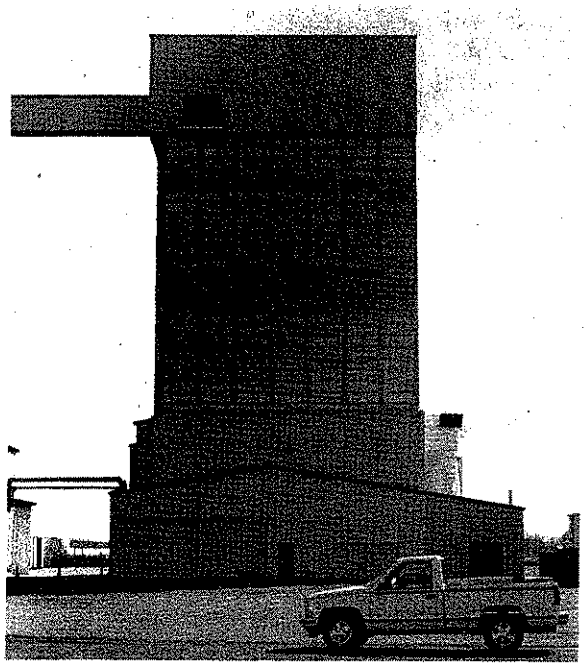

Figure 17. Storage bins for feed.

Figure 18. Screener for screening prior to load-out.

Just prior to bulk loadout or bagging, feed pellets are screened (Figure 18) to remove fines. Some feed mills may also screen the feed pellets after drying prior to fat coating and again after fat coating prior to storage for loadout. Fines are reclaimed and used as a feed ingredient. Almost all commercial catfish feeds are delivered to the farm in bulk by truck (Figure 19). Some feed is bagged (Figure 20).

Feed Types

Growout feeds

Catfish grown from fingerlings to marketable size are typically fed a floating feed (Figure 11) prepared as previously described. The feed size is usually about 3/16-inch in diameter. Traditionally, growout feeds for catfish contain 28 to 32% protein (Table 4).

Fry and fingerling feeds

Feeds of a small particle size [flours, meals, or crumbles (Figure 11)] are needed for feeding catfish fry and small fingerlings. Flour or meal-type feeds are usually prepared by either reducing the particle size of a steam-pelleted or extruded feed by grinding and screening to the appropriate size or by finely grinding feed ingredients to a particle size of less than 0.5 mm and mixing the ground ingredients. Crumbles are usually prepared by crushing (crumbling) pelleted feeds and screening for proper size. If flour or meal-type feeds are pelleted and then reground to the proper particle size instead of simply grinding and mixing, water soluble nutrients are less likely to be lost to the water. Since soluble vitamins are easily to be lost to the water, fry feeds should be overfortified with water soluble vitamins. Spraying fat on the surface

Table 4. Examples of typical catfish growout feeds.

	% of feed				
Ingredient	**(32%[a])**	**(32%)**	**(32%)**	**(28%)**	**(28%)**
Soybean meal (48%[a])	36.5	34.5	22.5	26.3	25.5
Cottonseed meal (41%)	10.0	12.0	27.5	10.0	10.0
Menhaden meal (61%)	4.0	–	4.0	4.0	–
Meat/bone/blood (65%)	4.0	8.0	4.0	4.0	8.0
Corn grain	22.9	22.4	21.1	30.6	31.4
Wheat middlings	20.0	20.0	18.0	22.5	22.5
Dicalcium phosphate	1.0	1.0	1.0	1.0	1.0
Lysine-HCl	–	–	0.275	–	–
Catfish vitamin mix	include	include	include	include	include
Catfish mineral mix	include	include	include	include	include
Catfish oil[b]	1.5	2.0	1.5	1.5	1.5

[a]Percentage protein.
[b]Sprayed on finished feed pellet to reduce feed dust (fines).

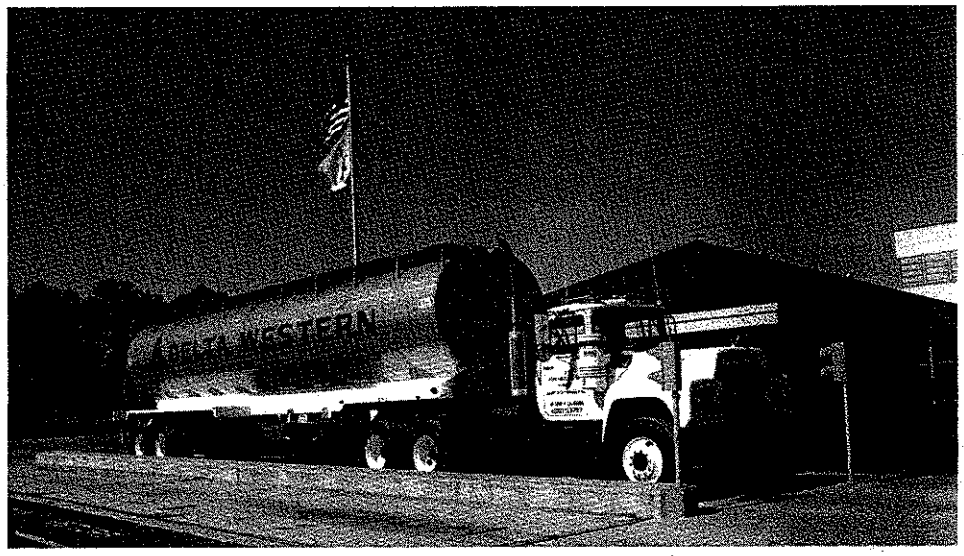

Figure 19. Typical truck for delivery of bulk feeds to catfish farms.

of meal or crumble feeds improves water stability and floatability and reduces nutrient loss to the water.

A typical catfish fry feed contains 45 to 50% crude protein, which is mainly composed of fish meal (Table 5). Fingerling catfish are fed crumbles or small floating pellets. Typical fingerling feeds contain 35% crude protein (Table 5), a part of which is supplied by fishmeal or a mixture of fishmeal and meat and bone/blood meal.

Broodfish feeds

Catfish broodfish are normally fed the same feed used for growout. A high protein (38%) feed has been available by special request for use with broodfish. However, there are no data that show that the high protein is necessary.

Table 5. Examples of typical catfish fry and fingerling feeds.

Ingredient	% of feed	
	Fry feed (50% protein)	Fingerling feed (35% protein)
Soybean meal (48%[a])	–	38.8
Cottonseed meal (41%)	–	10.0
Menhaden meal (61%)	60.2	6.0
Meat/bone/blood (65%)	15.3	6.0
Corn grain	–	16.1
Wheat middlings	19.0	20.0
Dicalcium phosphate	–	1.0
Catfish vitamin mix[b]	0.3	0.1
Catfish mineral mix[b]	0.1	0.025
Catfish oil[c]	5.0	2.0

[a]Percentage protein.
[b]Commercial mix that meets or exceeds requirements for catfish.
[c]Sprayed on after extrusion to reduce feed dust.

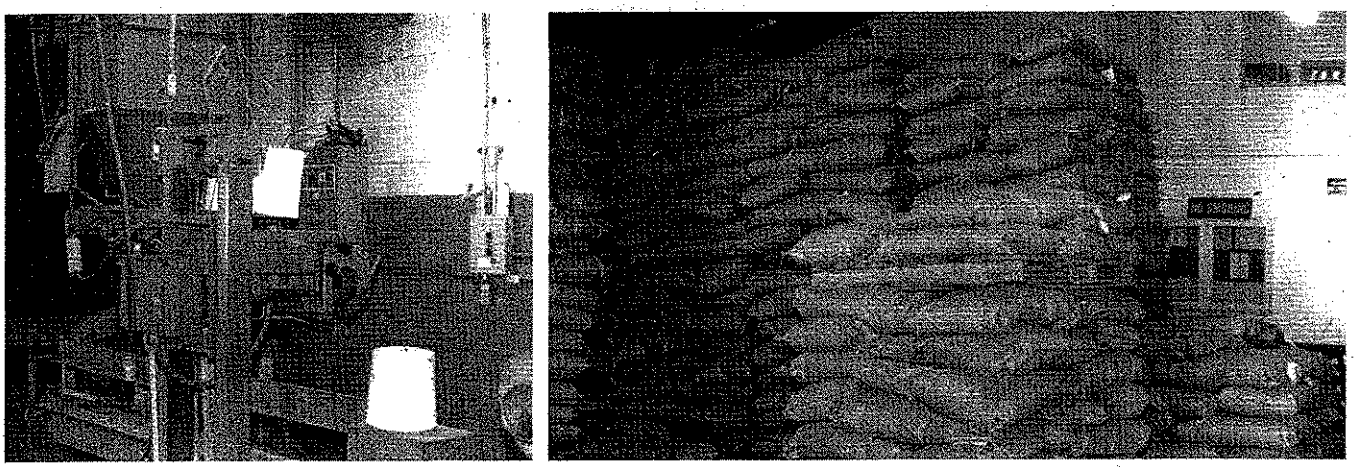

Figure 20. Feed bagger (left) automates the filling and sealing of bags of feed (right).

Table 6. Typical catfish winter feed and medicated feed.

Ingredient	% of feed	
	Winter feed (25% protein slow sink)	Medicated feed (32% protein with Romet)
Soybean meal (48%[a])	18.3	26.8
Cottonseed meal (41%)	10.0	10.0
Menhaden meal (61%)	4.0	16.0
Meat/bone/blood (65%)	4.0	–
Corn grain	35.1	23.0
Wheat middlings	25.0	20.0
Dicalcium phosphate	1.0	1.0
Catfish vitamin mix	0.1	0.1
Catfish mineral mix	0.025	0.025
Catfish oil[b]	2.5	1.5
Romet	–	1.65

[a]Percentage protein.
[b]Sprayed on after extrusion to reduce feed dust.

Winter feeds

Catfish do not feed well at temperatures below 70°F, although catfish may feed at temperatures as low as 50°F. Winter feeding of catfish is practiced by some producers to prevent weight loss and maintain health. A 25% protein slow sinking feed (extruded) is available commercially (Table 6). Manufacture of the slow sinking feed is as described under extrusion, except that the extruder is slowed and additional fat is added to the feed mix to decrease expansion when the feed pellet leaves the pellet die, thus achieving the slow sinking characteristic.

Medicated feeds

Presently, only two antibiotics, Terramycin™ (oxytetracycline, Pfizer, New York, NY) and Romet™ (sulfadimethoxine-ormetoprim, Hoffmann LaRoche Inc., Nutley, NJ) are approved by the FDA for use to treat fish bacterial infections. Medicated feeds containing these two antibiotics are available commercially. Terramycin is currently added to catfish feeds to provide the recommended dosage of 2.5 to 3.5 grams of active oxytetracycline per 100 pounds of fish per day, which corresponds to 11 pounds of active ingredient per ton of feed. Terramycin-medicated feed is steam-pelleted in a sinking pellet, because the antibiotics are heat-sensitive and are destroyed during extrusion. Romet has been added to catfish feeds at levels from 11 to 66 pounds per ton of feed, but the most commonly used level is 33 pounds per ton. The recommended dosage is 2.3 grams of active ingredients per 100 pounds of fish per day. The product is heat stable, so it can be used in a floating feeds. The level of fish meal should be increased to about 16% when manufacturing Romet-medicated feed to improve the palatability of the product to catfish.

Quality Assurance

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

Feed formulation

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

Ingredients

The purchasing agent ensures that high-quality ingredients are available on a timely basis at a reasonable cost by having an understanding of feed ingredients and by knowing which suppliers can consistently provide ingredients as needed. Working with the nutritionist and the production manager, the purchasing agent establishes and uses ingredient specifications to ensure that ingredients meet the standards desired.

Ingredients are inspected for color, odor, and texture prior to acceptance. Although subjective, visual and sensory inspection provides useful information on the quality of ingredients prior to use. An in-house test for moisture or toxins may be performed. Samples are taken for chemical analysis. Analyses are conducted to determine if ingredients meet specifications. Also, analyses may be conducted to determine presence of toxins, pesticides, or heavy metals.

Since chemical tests lag behind ingredient use, a particular ingredient will be used prior to receiving the analytical results. However, if specifications are not met, a deficiency claim is filed with the supplier. In addition to ensuring quality by inspecting ingredients, ingredient inventories are maintained, which provides information on the amount of an ingredient used over a certain time period. This can be used to check and correct errors in the manufacturing process.

Manufacturing

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

Finished feed

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

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