VI: FISH NUTRITION, FEEDS AND FEEDING

INTRODUCTION

The objective of feeding fish is to provide the nutritional requirements for good health, optimum growth, optimum yield, and minimum waste at reasonable cost for maximum profit. Nutritional and physical quality feed is the key to achieving production and economic objectives of 80:20 pond fish culture. Nutritional quality means the feed meets all the nutritional requirements of the fish through the inclusion of quality ingredients in proper proportions. Physical quality means the feed is fresh and in the form of a clean, firm pellet with water stability of >10 min.

FISH NUTRITION

Cultured fish require protein, lipids, energy, vitamins and minerals in their diet for growth, reproduction, and other normal physiological functions. The requirements vary somewhat among species and within species relative to stage of life cycle, sex, reproductive state and environment.

Nutrients of cultured fish may come from food sources, such as plankton, bacteria, insects and other fish from within the aquacultural ecosystem, and/or from organic matter and processed feeds added to the ecosystem. Foods are defined as natural sources of nutrients produced in the environment, and feeds are natural and manufactured sources of nutrients produced elsewhere and added to the environment. Fish with highly specialized feeding, habits, such as micro-filterers (e.g. silver carp), herbivores (e.g. grass carp) and piscivores (e.g. sea bass) may primarily or entirely depend on food while less specialized omnivores (e.g. common carp) readily take manufactured feeds and do not require any food in their diets. Where foods are insignificant, such as for the primary 80% species in 80:20 pond culture, nutritionally complete feeds are essential. Nutritionally complete means the feed meets all the nutritional requirements of the fish through the inclusion of quality ingredients in proper proportions. Only nutritionally complete, manufactured feeds are recommended for 80:20 culture.

Supplemental feeds (feeds supplementing foods), which are usually rich in protein but nutritionally incomplete, may be used to expand production in fishponds where foods are a major source of nutrition (levels 3 and 4; Table I-1). Supplemental feed may be a single ingredient product such as rice bran or multi-ingredient processed feed. Nutritionally complete feeds are required where foods are absent or are a minor source of nutrition (levels 5 and 6). Nutritionally complete feed will typically be a multi-ingredient pelleted feed produced through either a steam pelleting or extrusion process.

Protein and Amino Acids

Proteins compose approximately 70% dry weight of the organic material in fish tissue; therefore, protein content is one of the most important nutritional compounds of fish feeds.

Crude protein content is the general measure of fish feed quality, and is usually expressed in reference to specific fish feeds such as a "32% protein catfish feed" or a "36% protein fingerling ration." Usually, fish growth will be directly proportional to the protein level of its feed if the level is within the range of approximately 20 to 40% crude protein. Optimum dietary protein levels vary with fish species, stage of life, water temperature, food consumption, daily feed allowance, feeding frequency, quality of protein (amino acid composition), and quantity of non-protein energy.

Fish do not have a true protein requirement but require a balanced combination of the 20 major essential and nonessential amino acids that make up proteins. Fish utilize dietary proteins by digesting them into free amino acids which are absorbed into the blood and distributed to tissues throughout the body where they are then reconstituted into new specific proteins of the fish tissues. Protein in fish tissues is formed from all 20 major amino acids. Fish can synthesize some of these amino acids in their body but some they cannot and these, therefore, must be consumed. The 10 amino acids that fish cannot synthesize are the "essential amino acids" that must be provided in proper amounts in their diet. The essential amino acids required by channel catfish, common carp, and nile tilapia are the same required for all fish and animals. Although qualitatively they are the same or similar, quantitatively they are different (Table VI-1).

If any of the 10 "nonessential" amino acids are not consumed as such in the diet, fish can synthesize these in required quantities from other amino acids. It is not clear how effectively cultured fishes can utilize synthetic (crystalline) amino acids, such as free lysine and methionine, in their diets.

Proteins are present in all animals and plants in varying amounts and compositions of amino acid. However, each protein varies in its digestibility and content of available amino acids to the fish. Therefore, the amino acid composition and availability in feed ingredients may not be balanced and may be limiting relative to the requirements of a specific fish species (Table VI-1). The preferred sources of feedstuffs for providing protein for fish feeds are fish meal and soybean meal, because these products are high in percent crude protein, contain high levels of all essential amino acids, are universally available in high quantities and are reasonably priced.

Energy

Energy requirements and, more importantly, energy:protein ratio requirements for fish are not well established. Relatively less information is available for fish compared to farm animals except that fish require significantly less energy relative to protein. Metabolizable energy requirements for chickens and hogs are approximately 15 and 20 kcal/g crude protein, respectively, compared to approximately 9 kcal/g for warmwater fishes. Fish have lower dietary energy requirements because they do not have to maintain a constant body temperature, they use less energy in protein waste excretion (about 85% of nitrogenous protein wastes of fish are excreted through the gills as ammonia rather than through the kidneys as uric acid in chickens or urine in hogs), and fish require less energy than land animals to maintain position in water because of their neutral buoyancy.

Table VI-1. Amino acid requirements of channel catfish, common carp and nile tilapia and amino acid availability to channel catfish in five major feed ingredients (as fed basis).

Amino acid	Required for species[1] (% of feed) Catfish	Common carp	Nile tilapia	Availability for channel catfish by protein source[2] (% of ingredient) Fish meal[a]	Soy bean meal[b]	Cotton seed meal[c]	Rice bran[d]	Corn grain[e]
Arginine	1.38	1.37	1.34	3.41	2.93	3.81	0.68	0.35
Histidine	0.48	0.67	0.54	1.23	0.94	0.91	0.19	0.23
Isoleucine	0.83	0.80	0.99	2.51	1.62	1.09	0.40	0.24
Leucine	1.12	1.06	1.09	3.99	2.73	1.78	0.63	1.06
Lysine	1.63	1.82	1.63	4.08	2.52	1.20	0.46	0.24
Methionine + Cystine	0.74	0.99	1.02	1.90	1.05	1.05	0.28	0.19
Phenylalanine + Tyrosine	1.60	2.07	1.82	3.90	2.89	2.63	1.04	0.68
Threonine	0.64	1.25	1.15	2.19	1.36	1.06	0.38	0.24
Tryptophan	0.16	0.25	0.32	0.5[f]	0.5 [f]	0.45[f]	0.08[f]	0.06[f]
Valine	0.96	1.15	0.90	2.80	1.59	1.43	0.62	0.33

1 Modified from National Research Council. 1992. Nutrient Requirements of Warmwater Fish. Washington D.C. Natl. Acad. Sci.
2 Modified from Robinson, E. H. and R. T. Lovell, eds.l984.Nutrition and Feeding of Channel Catfish. So. Coop. Series Bull. No. 296.
a Menhaden fish meal, 92% dry matter, 61.1% crude protein
b Soybean meal, 90% dry matter, 44.8% crude protein
c Cottonseed meal, 91% dry matter, 41.1% crude protein
d Rice bran, 91% dry matter, 12.7% crude protein
e Corn grain, 89% dry matter, 9.6% crude protein
f Tryptophan estimated based on assumed 80% availability

Metabolic energy is available to fish from proteins, lipids and carbohydrates. The amount of digestible energy (DE) required by fish is affected by species, life stage, sex, activity level, temperature, various water quality and other environmental factors. For energy needs cultured fish use proteins and lipids primarily and carbohydrates secondarily while land animals use carbohydrates and lipids primarily and proteins secondarily. Warmwater fishes can digest about 85% of gross energy in fish meal and other animal feedstuffs, which consist mainly of proteins and lipids, and about 70% of gross energy in soybean meal and other oilseed meals, which come partially from crude fiber (carbohydrates). The gross energy, primarily starch, in uncooked corn is approximately 95% digested by hogs but only 26% and 45% digested by channel catfish and nile tilapia, respectively. Cooking corn increases its digestibility by channel catfish and tilapia to about 58% and 72%, respectively. Carbohydrate digestibility is higher in extruded feed than in compressed feed, because more heat and moisture are used in the extruding process.

Neither dietary energy deficiencies nor excesses will have a major effect on fish health, and neither is likely to occur in standard practical fish feeds made from commonly available ingredients. However, meeting optimum energy requirements is important because: 1) if a diet is deficient in energy relative to protein, a proportionate amount of dietary protein will be used for energy rather than building tissue, because energy needs for body maintenance and physical activity must be satisfied before energy and remaining protein are available for growth; and 2) conversely, if a diet contains excess energy the fish may become satiated (hunger is satisfied) before they consume necessary amounts of protein, vitamins and other nutrients for optimum growth and good health. Hunger is satisfied when a fish has consumed the calories it wants regardless of the amount of other nutrients it has consumed. Excess energy relative to protein may cause deposition of large amounts of visceral and body fat.

Optimum ratios of dietary digestible energy to crude protein for optimum fish growth vary somewhat between species and size (weight) among other factors already mentioned. At feed protein levels of about 30 to 36%, energy requirements of 8.5 to 10 kcal DE/g of protein (2,500 to 3,800 kcal/kg of feed) are recommended for feeds of channel catfish, common carp and nile tilapia for optimum growth in ponds from about 25 to 500 g.

A balanced diet for cultured warmwater fish should include lipids, both for supplying energy and essential fatty acids. Knowledge of fatty acid requirements of warmwater fishes is incomplete. Nevertheless, evidence supports a hypothesis that the more unsaturated lipids from vegetable and fish oils are superior to more saturated lipids from terrestrial animals. A blend of saturated and unsaturated lipids can be used in warmwater fish feeds. Coldwater fishes, however, must have highly unsaturated lipids in their diet.

Vitamins

Vitamins are organic compounds required in trace amounts and are essential for normal fish growth, reproduction and general health. Fish cannot synthesize vitamins and must consume them in their diet. Fish raised in intensive culture systems must be fed nutritionally complete feeds containing vitamin supplements. Minimum requirements for most of the 15 essential vitamins have been established for channel catfish, common carp and nile tilapia (Table VI-2). Although determined generally for fingerling fish, the requirements are probably sufficient for larger fish as well. The recommendations account for vitamin losses during feed processing and normal deterioration for up to three months in proper storage. They are also adjusted for differences in individual vitamin requirements because of species, stage of life cycle (specifically from 25 to 500 g), growth rate, feed formulation, disease, stresses resulting from normal fluctuations in the environment, bioavailability, and metabolic response (growth, disease resistance, stressor response).

Table VI-2. Vitamin premix for processed feeds for channel catfish, common carp and nile tilapia cultured in ponds.

Vitamin	Amount / ton of feed
Vit.A	5.5 million (active) IU
Vit. D3	2.0 million (active) IU
Vit.E	50 thousand IU
Vit.K	10 g
Thiamine (Vit. B1)	20 g
Riboflavin (Vit. B2)	20 g
Pyridoxine (Vit. B6)	10 g
Niacin (nicotinic acid)	100 g
Pantothenic acid	50 g
Choline chloride (70%)	550 g
Folic acid	5 g
Vit. B12	1 g
Biotin	1 g
Inositol	100 g

Ascorbic acid (vitamin C) is probably the first limiting vitamin in the diet of cultured fish, because most commercial feed ingredients do not contain the vitamin and its relative instability in processing and storage. It is a critical nutrient in fish feeds because of its function in the immune system, in detoxifying toxic chemicals and its many physiological functions as a metabolic reducing agent. Table VI-3 shows the effect of increased levels of ascorbic acid on resistance of bacterial disease in catfish. Because fish tissue becomes saturated at approximately 500 mg of ascorbic acid/kg feed, the use of higher levels is probably unnecessary.

Table VI-3. Mortality of channel catfish fed various levels of ascorbic acid and infected with the bacterium Edwardsiella ictaluri.

Vitamin C (mg/kg feed)	Mortality within 8 days (%)
0	100
60	70
150	35
300	15
3000	0

Vitamins are relatively unstable and a matter of major concern in feed processing, handling and storage. Some vitamins (e.g. vitamins C, A, and D3) are highly vulnerable to being destroyed during processing and storage while others (e.g. vitamins E and the B-complex) are not. Causes of vitamin destruction include:

1. Heat and moisture especially during feed processing (up to 60% of ascorbic acid may be destroyed during normal extrusion processing);
2. Natural oxidation destroys sensitive vitamins of foods, feed ingredients (before processing), vitamin premixes and processed feeds. Natural oxidation is accelerated by heat, moisture, and the presence of oxidants such as rancid fats and metals. Antioxidant agents, such as ethoxyquin coated over the vitamin to stabilize oxidation, have been only partially successful;
3. Anti-metabolites in the feeds and ingredients;
4. Leaching of vitamins from the feed into the water prior to fish consumption.

The effects of vitamin deficiencies in cultured fish are numerous and some are critical. Table VI-4 gives principal vitamin deficiency signs for channel catfish, common carp and nile tilapia, which would be the same or similar for other warmwater species. However, the most prevalent deficiency signs for most vitamins and other nutrients are reduced growth, poor appetite and lethargy. Therefore, these signs are not included unless no other signs have been reported.

Vitamins are contained in all fish foods and feed ingredients. However, these are highly variable and unpredictable in content and are, for the most part, disregarded when formulating a nutritionally complete feed. Vitamins, except ascorbic acid, are added to the feed mix as a vitamin premix, which is a package of individual vitamins in prescribed amounts in a custom made concentrated mixture. Vitamins must be fresh (100% potent) when incorporated into the feed for them to be effective at the recommended amounts. To assure vitamin activity, vitamins must be fresh when packaged, individually and/or collectively stabilized to resist decomposition, packaged in air tight, vacuum sealed containers, maintained in a cool (even frozen) environment until used, incorporated into a feed within six months of packaging, and the feed stored in a cool, dry environment and used within three months.

Ascorbic acid is usually not included in a vitamin premix but added as a separate ingredient. In its natural or pure form ascorbic acid is highly sensitive to heat and moisture. Unless protected it will deteriorate relatively quickly, especially during feed processing.

Minerals

Mineral supplements are required in nutritionally complete fish feeds. However, the specific requirements for most minerals have not been established. Fish require up to 22 different minerals for tissue formation, metabolic processes and to maintain osmotic balance between their internal fluids and their water environment. Some minerals are essential in their diet. Some dissolved minerals, such as calcium, can be exchanged between the body fluids and the surrounding water across sill membranes. Dietary mineral deficiencies in cultured fish have not been as well established as with vitamins. Known and suspected deficiencies include reduced growth rate, poor appetite and skeleton deformities.

Table VI-4. Vitamins required by channel catfish, common carp or nile tilapia and their principle deficiency signs.

Vitamin	Principal vitamin deficiency signs
Vitamin A	Exophthalmus (popeye); hemorrhagic eyes: eye lens displacement: other vision problems; light skin Color: twisted opercula; hemorrhages in fins, skin and kidney; abdominal fluid; excess tissue fluid
Vitamin D_3	Low bone ash, calcium and phosphorus
Vitamin E	Lack of sexual coloration (tilapia); light skin color; reduced reproductive activity; muscular dystrophy; popeye; kidney and pancreas degeneration; ceroids in viscera and kidney; fatty liver; fluid accumulation beneath skin in abdomen
Vitamin K	Skin hemorrhages; reduced blood coagulation; anemia
Thiamin (B_1)	Disequilibrium; lethargy; poor appetite; dark coloration (catfish) or light coloration (carp);subcutaneous hemorrhage; hypersensitivity (nervous disorder);convulsions; fin congestion
Riboflavin (B_2)	Cataract (opaque eye lens); light sensitivity; short, stubby body: anemia; skin and fin hemorrhages; dark coloration; poor appetite
Pyridoxine (B_6)	Erratic swimming; nervous disorders; convulsions; muscular spasms when stressed; gyrations; tetany; lethargy; rapid breathing; flexing of opercles;iridescent black coloration
Pantothenic Acid	Clubbed, fused gill lamellae and filaments; eroded gill membranes, lower jaw, fins and barbels; mummy-textured skin; popeye; anemia; flabby body tissues
Niacin	Light sensitivity; tetany (stress induced); reduced coordination; lethargy; skin and fin lesions and hemorrhages; deformed jaws; popeye; anemia; loss of appetite
Folic acid	Emaciated; lethargy; anemia; dark coloration; reduced immunity; weak caudal fin
Vitamin $B\text{-}_{12}$	Anemia; poor appetite
Ascorbic acid	Light or dark skin color; deformed (curved) spine; distorted support cartilage of the eyes, gills and fins; other skeletal deformities; increased susceptibility to disease (especially bacterial); slow wound healing; hemorrhagic skin, liver, kidney, intestine and muscle
Biotin	Light skin color; increased skin mucous; degenerated gill lamellae; anemia; enlarged, pale liver; lesions in colon; nervous disorders (noise and movement sensitivity); loss of appetite
Choline	Enlarged, fatty liver; hemorrhagic areas in kidney and intestine; poor feed efficiency
Inositol	Anemia; slow rate of gut emptying; distended stomach; fin erosion

The most common deficiencies are associated with calcium and phosphorus, the two most required and most studied minerals. Most freshwater fish can absorb sufficient calcium from the water unless calcium carbonate content of the water is below 5 mg/1. Therefore, supplemental calcium is not required in mineral premixes of fish feeds. However, supplemental phosphorus is required in the feed, because the concentration of dissolved phosphorus in most freshwaters is too low to be a significant source for fish.

Bound phosphorus in plant ingredients is only partially available to fish (Table VI-5). Phosphorus requirements of fish vary only slightly among species and are reported as available phosphorus in the diet. The available phosphorus requirements for channel catfish, common carp and nile tilapia are 0.45%, 0.45% and 0.60%, respectively. Minerals are sometimes listed as major or trace nutrients based on relative requirements (Table VI-6). Some required minerals, such as sodium and potassium, are present in sufficient amounts in feed ingredients and do not need to be added as supplements. Recommended amounts of minerals for a model complete fish feed are given in Table VI-7. Mineral deficiency signs in fish (Table VI-8) are similar to some of the other nutrient deficiencies and are essentially impossible to isolate.

Table VI-5. Phosphorus availability in some common feed ingredients.

Feed ingredient	Available phosphorus (» % of total phosphorus)
Grains	33
Soybean meal	40
Fish meal	60 (catfish); 25 (carp)
Monocalcium phosphate, Ca(H2P04)2	95 (catfish); 95 (carp)
Dicalcium phosphate, CaHP04	80 (catfish); 45 (carp)
Tricalcium phosphate, Ca3(P04)2	50 (catfish); 15 (carp)

Table Vl-6. Minerals required by fishes.

	Major (7)		Trace (15)	
	Calcium	*	Iron	Fluorine
*	Phosphorus	*	Iodine	Aluminum
*	Magnesium	*	Manganese	Nickel
	Sodium	*	Copper	Vanadium
	Potassium		Cobalt	Silicon
	Chlorine	*	Zinc	Tin
	Sulfur	*	Selenium	Chromium
			Molybdenum	

*These minerals must be supplementally added to produce nutritionally complete feeds.

Table VI-7. Mineral premix for processed feeds for channel catfish, common carp and nile tilapia cultured in ponds.

Mineral	Amount / ton of feed
Copper sulfate (CuSO4)	20 g
Iron sulfate (FeSO4)	200 g
Magnesium carbonate (MgCO3)	50 g
Manganese carbonate (MnCO3)	50 g
Potassium iodide (KI)	l0g
Zinc sulfate (ZnS04)	60 g
Sodium chloride (NaCl)	5 g
Cobalt carbonate (CoCO3)	1 g
Sodium selenite (Na2SeO3)	2 g
Ethoxyquin (antioxidant)	125 g

* Phosphorus is not included in mineral premixes for fish, but it is instead supplemented as a separate feed ingredient, preferably in the form of monocalcium phosphate Ca(H2PO4)2 at 10 kg/ ton.

Table VI-8. Potential dietary mineral deficiency signs in channel catfish, common carp and nile tilapia

Mineral	Deficiency signs
Phosphorus	Poor growth and bone mineralization abnormal spine; abnormal calcification of ribs and pectoral fine rays; deformed head; increased carcass fat and fatty liver
Magnesium	Poor growth; emaciated; lethargy; flaccid (degenerated) muscles; high mortality
Iron	Anemia
Copper	Improper collagen and bone development
Iodine	Goiter
Zinc	Depressed growth and appetite; erosion of the skin and fins; cataracts
Manganese	Depressed growth; abnormal caudal fin
Selenium	Depressed growth; muscular dystrophy
Sodium, potassium, and chlorine	None yet produced

FISH FEEDS

Feeds for Pond Fish

Feeds for fish intensively cultured in ponds must be nutritionally complete and should be nutritionally balanced. Although some few omnivorous fish, such as nile tilapia, may obtain some essential nutrients by filtering plankton from nutrient rich waters, they still need a complete diet as if they were being cultured in food-free waters. All of the nutrient requirements for all cultured fish are not known at present but the requirements for channel catfish, common carp and nile tilapia are generally acceptable for other similar warmwater species.

Nutritionally complete, dry pelleted feeds are required for intensively farmed channel catfish, common carp and nile tilapia. Natural fresh feeds are not recommended. No forms of natural fresh feeds are recommended for pond fish except "grass" (grass and other forms of fresh vegetation) that may be used with pelleted feeds for grass-feeding fish such as grass carp. The use of raw, "trash fish", usually whole fish with low market value or by-products from fish processing, is strongly discouraged. Also discouraged is the use of natural ingredients such as raw or cooked corn and cassava. A relative comparison of major factors between natural fresh feed sources and dry pelleted feeds is presented in Table VI-9.

Table VI-9. Comparison of major factors between natural and pelleted feeds.

Factor	Natural feed	Pelleted feed
Moisture content	High (» 80%)	Low(» 10%)
Nutritional quality	Low	High
Nutritional quantity	Low	High
Waste quantity	High	Low
Environmental pollution potential	High	Low
Disease causing potential	High	Low
Feed efficiency	Low	High
Cost per benefit	High	Low

Pelleted fish feeds are either compressed or extruded based on their manufacturing process. While they are formulated from the same ingredients, they are fundamentally different in that compressed pellets immediately sink when placed in water and extruded pellets float on the surface. Comparative physical differences in the two types of feeds are presented in Table VI-10. Although extruded feeds are more expensive than compressed feeds of the same formulation, their advantages allow them to be significantly more economically efficient.

Manufacture of Pelleted Feeds

Quality control in the selection of feed ingredients is important in the manufacture of pelleted feeds. A finished feed can be no better than the quality of its ingredients. Available VI-10.

Some relative advantages and disadvantages of extruded vs. compressed pelleted fish feeds.

Factor	Extruded pellet value
Fish production	
Float vs. sink	Advantage
Water stability	Advantage
Pellet binding	Advantage
Feed loss in pond muds	Advantage
Dust (unbound feed material)	Advantage
Feed conversion efficiency	Advantage
Feed management (allowance adjustment)	Advantage
Nutrient digestibility	Advantage
Bacteria and toxins in feed	Advantage
Impact on water quality	Advantage
Water quality management	Advantage
Disease incidence	Advantage
Processing temperature on nutrients	Advantage -- digestibility Disadvantage -- vitamin loss
Management value	Advantage
High fish yield potential	Advantage
Purchase cost	Disadvantage
Economic efficiency	Advantage
Feed manufacturing	
Capital cost	Disadvantage
Processing cost	Disadvantage
Utility cost	Disadvantage
Equipment wear (e.g. die wear)	Advantage
Least cost options	Advantage

nutrient content, digestibility, and absence of contamination from pesticides or other toxins are primary quality attributes.

Ingredient selection for feeds is based on meeting nutritional requirements at least cost. Selection is based on maximum-minimum limits in which specific ingredients may be incorporated into feeds. Maximum limits are usually specified because of toxic natural substances (e.g. gossypol in cottonseed meal) they may contain. Minimum limits are usually specified because of a special function of the ingredient such as to enhance palatability or pellet stability in water. Fish meal is sometimes recommended in minimum amounts to balance the amino acid composition of plant proteins. Wheat by-products, rice and other starchy ingredients may be recommended in minimum amounts to improve pellet durability and water stability as well as to provide energy.

Ingredients preferably should be ground as finely as practical. Decreasing particle size increases digestibility and pellet durability and water stability. Mineral premixes may be added prior to grinding while vitamin premixes should be added post grinding during the subsequent ingredient mixing phase. Additives are best incorporated into the feed mixture by first diluting and blending them into 4 to 5% of the mixture and then blending that into the total mash.

Ingredients for compressed and extruded pelleted feeds are similar, although a higher allowance of heat sensitive vitamins may be added to the pre-extruded mash. Preparation of the mash is the same for both types of feed. However, the manufacturing processes are different with extrusion requiring a more elaborate process (Table VI-11).

Table VI-11. Generalized comparison of compressed and extruded fish feed pellet processing.

	Processing Activity	
Processing stage	Compressed pellets	Extruded pellets
Preconditioning	Steam and/or water added mash to 18% moisture at » 80°C.	Steam and/or water added to mash to 25% moisture at » 100°C
Pelleting	Hot mash passes through pelleting chamber and is predded through pellet die.	Hot mash passes through barrel of the extruder and under increased heat (» 140°C) and » 6 kg/cm2 pressure, mash is forced through die where pressure immediately drops and super-heated moisture vaporizes causing expansion of the pellets.
Drying	Non-heated air forced over hot pellets immediately after die, reducing moisture to ≤ 10% and cooled to air temperature.	Immediately after extrusion, pellets are passed through a heated drying tunnel to reduce moisture to £ 10%, then allowed to cool to air temperature.
Post-pelleting oil spray	Oil is usually incorporated during processing and not sprayed on after pelleting.	Oil is sprayed over surface of pellets sprayed on after immediately after extrusion.

Fish Feed Formulation

Feed formulas for dry pelleted feeds proven for pond fishes have been developed as fixed formulations, least cost formulations or a combination of the two. Fixed formulations are those feeds produced from set formulations of specific ingredients without significant alteration of those ingredients regardless of cost. Table VI-12 is an example of a fixed formula. Least cost formulations are those feeds produced from the selection of any number of different ingredients that collectively must meet minimum nutritional restrictions. Table VI-13 is an example of least cost formulation restrictions based on the fixed formulation.

Table VI-12. Model of a nutritionally complete (32% protein) feed for channel catfish, comon carp and nile tilapia cultured in ponds.

Ingredient	Kg/ton of feed
Fish meal (61% protein; menhaden)	100
Soybean meal (44-48% protein)	400
Wheat flour (#4)	225
Rice bran (or corn or wheat shorts)	140
Cottonseed meal (or equivalent)	52
Rapeseed meal (or equivalent)	50
Fish (or animal) oil	20
Vitamin premix (wheat flour carrier to 1.5 kg) (same as Table 2)	1.5
Mineral premix (zeolite as carrier to 1 kg) (same as Table 8)	1.0
Monocalcium phosphate $Ca(H_2PO_4)_2$	10
Ascorbic acid (coated; ascorbic acid phosphate form preferred)	0.5
	1,000

Total Ingredients
Proximate analysis:

Crude protein	32%
Crude fat	6%
Available phosphorus	0.8%
Digestible energy	» 2,900 kcal/kg feed
	» 9.5 kcal/g crude protein

Table VI-13. Least cost formulation restrictions for a 32% crude protein feed for use in pond production of channel catfish, common carp and nile tilapia.

Qualifier	Restriction	%
Protein	Minimum	32.00
Fish meal, menhaden	Maximum	10.00
Soybean meal	Minimum	30.00
Cottonseed meal	Maximum	10.00
Digestible energy (kcal/kg)	Minimum 2900	-
Fat	Maximum	6.00
Wheat, extruded pellet	Minimum	2.00
	compressed pellet (for binding) 10.00	Minimum
Vitamin premix (standard complete)	-	0.10
Mineral premix (standard complete)	-	0.10
Phosphorus, total	Minimum	1.20
Phosphorus, available	Minimum	0.80
Ascorbic acid, coated form	Minimum	0.05
phosphate form	Minimum	0.02

* Vitamin and mineral premixes should contain the substances and amounts give Tables 2 and 7, respectively.

FEEDING POND FISHES

Objective

The purpose of fish farming is to economically produce crops of fish. Economic feasibility is obtained by maintaining a productive pond ecosystem with sufficient nutritional inputs to achieve optimal crop yields. The objective of feeding fish in ponds is to economically provide proper nutrition for fish growth and good health with minimal metabolic waste and ecosystem pollution for maximum profit. Requirements for achieving the objective are providing proper quality and quantity feed and using proper feeding methods. Not all cultured fishes will take pelleted feeds and some will not take manufactured feeds of any type. The following are general rules regarding fish behavior toward manufactured feeds based on their feeding behavior.

1. Omnivorous fish will readily take both floating and sinking pellets;

2. Bottom dwelling omnivorous fish may take longer than mid-water dwelling omnivores to train to take floating pellets;

3. Specialized omnivores, and omnivores with strong herbivorous or predaceous preferences, may take dry pellets only sparingly, but readily take moist pellets or other feed forms;

4. Strictly planktivorous and piscivorous fish usually will not take dry pellets.

Channel catfish, common carp, nile tilapia, and probably all omnivorous freshwater species, readily learn to take both sinking and floating pelleted feeds. Herbivorous species (e.g. grass carp) and some specialized filter feeding species (e.g. bighead carp) will quickly learn to take pelleted feed, but their production performance with pelleted feed may be less than with normal food diets. Most predaceous species will either not take feed or will perform poorly if normal foods are lacking.

Feed Quality

Feeds for 80:20 pond fish culture must be nutritionally complete, water stable for a minimum of 10 minutes, and used within 4-6 weeks of being freshly manufactured. Only pelleted feeds are recommended, and these may be either sinking or floating types, but floating pellets are the preferred type where available.

Fish feeds are judged on both their nutritional and physical qualities. However, farmers are at the mercy of feed manufacturers and others for accurate assessments of feed quality. In most countries manufacturers are required to tag feeds with information on proximate analysis, list of ingredients, processed date and possibly other information. However, such information does not include facts relating to actual quality and quantity of vitamins and other ingredients, possible toxins in the feed, water stability time and other critical facts. Farmers must rely on information provided by the manufacturer, feed distributor, extension agents, other farmers and their own experiences. The following is a checklist of factors that a farmer should check for each shipment of feed:

1. Mold (no amount acceptable) - detectable by sight and odor contains toxins that affect nutritional properties and cause disease, poor growth and high FCR;

2. Fines or feed dust (£ 1 % acceptable) - detectable by sight, blowing a hand-full of feed, or adhering to skin after hand and arm are pushed about 15 cm into the feed - causes direct feed loss, poor water stability time, pollution of water and high FCR;

3. Poor water stability (10 minutes minimum acceptable for compressed pellets and 1 hour for extruded pellets) - detectable by placing a few pellets in a glass of water and timing break-up into particulate matter - causes direct feed loss, pollution of water and high FCR;

4. Loosely bound - detectable by crushing with fingers or with little pressure between 2 objects causes poor water stability and its associated effects;

5. Coarsely ground ingredients - detectable by sight; no ingredient except corn should be large enough to be recognized - coarsely ground ingredients result in incomplete digestion, increased waste and pollution, higher FCR and decreased profit;

6. Feed tag information - be sure the information on the feed tag is consistent with the feed tag prototype in Table VI-14.

Table VI-14. Sample feed tag containing information on guaranteed analysis, ingredients, and feeding directions.

FLOATING FINGERLING
CATFISH FOOD

GUARANTEED ANALYSIS
Crude Protein, minimum...36.0%
Crude Fat, minimum...3.0%
Crude Fiber, maximum...6.0%

INGREDIENTS
Soybean Meal, Wheat Midlings, Ground Corn, Fish Meal, Corn Gluten Meal, Meat and Bone Meal,Animal Fat (stabilized with BHA), Limestone, Dicalcium phosphate, Salt, Vitamin A Acetate, Vitamin D-3 Supplement, Vitamin E supplement, Menadione Sodium Bisulfite Complex (source of Vitamin K activity). Ascorbic Acid (source of Vitamin C), Choline chloride, pantothenic Acid, Riboflavin Supplement, Flolic Acid, Niacin.Thiamin, Vitamin B-12 Supplement, Pyridoxine Hydro-chloride, Biotin, Traces of : Manganous Oxide, Zinc Oxide, Iron Sulfate, Iron Carbonate, Co-balt Carbonate, Copper Oxide, Copper Sulfate, Calcium lodate. Sodium Selenite, Ethoxyquin (a preservative). Calcium Propionate.

FEEDING DIRECTIONS

Fish producers would like for feed to be 100% ingested, 100% digested and 100% assimilated, but only 100% ingestion is possible and a worthy goal. Consider that with a good quality feed and feeding program, optimum FCR for growout of most fish species from about 40 to 600 g should be about 1.5 ± 0.2 (lower FCR is possible and may be legally required within a few years). Higher FCR is excessive and costly. Within limits the higher the feed quality the:

1. Lower the FCR;

2. Higher the growth fate;

3. Higher the yield;

4. Higher the fish health and lower the incidence and severity of disease;

5. Lower the quantity of waste into the environment;

6. Higher the water quality;

7. Lower the frequency and amount of aeration and water exchange;

8. Lower the probability of fish off flavor;

9. Higher the feed price but lower the cost of production.

Feeding Rates, Allowances and Schedules

Feeding rate values are based on a percentage of the total weight or biomass of feed-taking fish in a culture environment. Rates vary according to many factors including species, size, stage in life cycle, water temperature, other water quality variables, feed density, nutritional level and management system. For a given species, feeding rates are routinely affected by fish size and water temperature (Table VI-15). Smaller fish of a species will eat more feed and more often than larger fish. Fish of all sizes will eat progressively less and eventually stop taking feed as water temperature decreases or increases beyond their optimum temperature range. Optimum production temperature for most warmwater fishes is approximately 28°C with a range between 25° and 30°C.

Feed allowance is the amount of feed that can be given to cultured fish per pond area per day. The feed allowance is limited by the effect of feed metabolism on pond water quality. As feed quantity is increased, water quality decreases, with low dissolved oxygen (DO) usually becoming the first water quality factor to affect fish. Limiting feed amounts, termed "maximum safe feeding allowances," are generally known for aquaculture systems, and are usually based on some minimum DO level expected during a daily cycle (e.g. 3.0 mg/1 DO at dawn). Because many factors affect water quality other than simply feed quantity, there is no sure means of accurately predicting the magnitude of DO and water quality deterioration as a result of a measured amount of feed given to the fish. Therefore, maximum "safe" feeding allowances are only guidelines, and at times may be "unsafe."

Daily feed allowances are limited by environmental factors and efficiency of the water quality management system employed. Table VI-16 gives recommended feed allowance ranges and expected fish yields for each of three water quality management levels. A maximum sustainable optimum for most farm situations will probably be a daily feed allowance of about 80 kg/ha and expected yield of about 5,000 kg fish/ha. Farmers should not feed in excess of 120 kg/ha/d unless they have very reliable high quality and quantity emergency water supplies.

Optimum feeding rates of fish in intensive cultures usually mean feed allowances of near 100% satiation, which is the total amount of feed that feeding fish will consume at a feeding before they stop taking feed. Optimum feed allowance per feeding and per day to balance growth and FCR is about 90% satiation; 80% satiation feeding gives lower FCR but slower growth; 100% satiation feeding results in maximum growth but higher FCR. Pond fish usually require no more than 10 minutes to consume a feed allowance. Any feed not

Table VI-15. General daily feeding rate and frequency guide for production of channel catfish, Common Carp and nile tilapia in ponds using a 32% protein pelleted feed at 28°C water temperature.

	Channel catfish		Common carp		Nile tilapia	
Fish mean weight (g)	Feed rate (%)	Frequency (x/day)	Feed rate (%)	Frequency (x/day)	Feed rate (%)	Frequency (x/day)
25	4.00	2	4.50	3	4.50	3
50	3.50	2	4.00	3	3.70	3
75	3.20	2	3.60	3	3.40	3
100	3.00	2	3.30	3	3.20	3
150	2.80	1	3.10	2	3.00	2
200	2.50	1	3.00	2	2.80	2
250	2.20	1	2.60	2	2.50	2
300	2.00	1	2.40	2	2.30	2
400	1.60	1	2.10	2	2.00	2
500	1.40	1	1.70	2	1.70	2
600	1.20	1	1.40	2	1.40	2

* Calculate feed allowance and adjust for water temperature differences as follows (temperature measured at 50-cm depth):

at £ 15°C feed at 1 % rate 1 x/day only 3 x/week
at 16 -19 °C feed at 60% of calculated allowance 1 x/day everyday
at 20 -24 °C feed at 80% of calculated allowance 1 or 2 x/day everyday
at 25 -30°C feed at 100% of calculated allowance maximum frequency everyday
at 31-32°C feed at 80% calculated allowance
at > 33 °C feed only what fish are observed to take-such temperatures should be avoided.

consumed when fish stop taking feed is in excess of satiation. Satiation is determined by either an estimate of standing crop or by observed feeding behavior. Feeding at >100% satiation contributes excessively to pollution and increases costs without benefits for feed and water management. Neither <80% nor >100% satiation feeding is desirable, but slight underfeeding would be preferable to overfeeding. However, overfeeding is observed to be much more common than underfeeding, especially among farmers with limited experience using high quality feeds.

In typical 80:20 pond cultures, daily amounts of feed per pond area increase geometrically from minimum amounts of only 5% of maximum safe rate per day immediately after stocking to 100% of maximum safe rate for the last several weeks before harvest. However, in traditional multiple-stock, multiple-harvest pond culture systems, daily amounts of feed per area of pond water should be increased and decreased proportionately with each stock and harvest. In these systems minimum feed amounts are often as high as 35% of maximum, but maximum amounts should never be above 100% of the maximum safe rate per day.

Feed allowance, in weight of feed per pond area per day (kg/ha/d), is calculated by multiplying the total standing crop of feed taking fish (i.e. collective total weight of the 80% species) by the feeding
rate. For example;

1,460 kg fish/ha standing crop x 2.3% feed rate = 34 kg feed/ha/d

Note that daily feed allowances increase but feed rates decrease as fish grow larger.

<u>Feeding schedule</u> refers to the specific time(s) at which the feed allowance is given to the fish The feeding frequency for a given species during optimum growing temperatures will vary according to size or stage of life cycle from up to 12 times/day for newly hatched fry to 3 or 4 times/ day for fingerlings, 1 to 3 times/day for growout production fish (Table VI-16) and 1 time/day for brood fish. Multiple daily feedings may increase growth rate, especially for fishes that do not have stomachs (e.g. common carp and nile tilapia), but multiple feedings may not improve feed conversion efficiency of larger growout size fish (>100 g). To demonstrate this point, nile tilapia were raised from approximately 45 to 3400 g in low-volume cages suspended in a reservoir with high water quality (Qian Dao Zhejiang, China). The tilapia were stocked at 400 fish/m3 in 16 cages. Fish in half the cages were fed 2 times/day at 9.5-hour intervals, and fish in the other half were fed 4 times/day at 2.5-hour intervals. After 140 feeding days no observed differences resulted in production performances of yield growth rate, survival and feed conversion values between tilapia fed daily rations in 2 feedings or 4 feedings. Economic differences favored 2 feedings/day because of only half the labor requirement. Caged fish are assumed to benefit more from multiple feedings than pond fish.

Fish in growout production in ponds should normally be fed during daylight hours from about 2 hour after sunrise to about 2 hours before sunset, but never at night. Feeding during cold weather to achieve growth and disease tolerance has received mixed results. Some growth may be obtained, but it is unlikely to be profitable. Winter feeding to improve channel catfish resistance to disease, instead appeared to actually make them more susceptible. Table VI-16 contains recommendations for cold weather feeding for 80:20 culture.

Table VI-16. Typical fish yield ranges for recommended daily feed allowances and related water quality management methods.

Level	Water management Aerate	Feed Flush	Fish yield (kg/ha/day)	(kg/ha range)
A	Limited	No	30- 60	2,500 - 4,000
B	Yes	Limited	60- 90	4,000 - 6,000
C	Yes	Yes	90- 120	6,000 - 8,000

Feeding Methods

Methods of feeding pond fish are designed to offer the daily feed allowance in a way that it will be 100% consumed by the fish. Accomplishing this objective requires water stable feed, optimum feed allowance (³ 80% to £ 100% satiation) and proper feeding methods. Pelleted feeds must be water stable for at least 10 minutes before they begin to erode and fall apart.

Determining optimum feed allowances for each feeding time per day is a simple concept but sometimes a difficult practice. The concept is to establish the 100% satiation point. One method to do this is to feed the fish at each feeding time for one day carefully measured amounts of feed until the fish stop eating. The amount of feed consumed to the point they stop feeding is considered 100% satiation and the maximum end point for that feeding time. Repeat the process at the next feeding time(s) for that day. The 100% satiation amounts will probably be different at each feeding time. Now that 100% satiation amounts have been established for each feeding time for that day, the same amounts should be fed at the corresponding feeding times for the next 7 to 14 days when new 100% satiation feed allowances would be determined. On each successive day during the 7 to 14 days, the set feed amounts would become progressively less than 100% satiation and by the 14th day would be near 80% satiation or the minimum end point of the feed allowance optimum range. Feed allowance adjustment is appropriate any time overfeeding or underfeeding is obvious. Underfeeding is preferable to overfeeding but neither is desirable.

When using floating feed, the 100% satiation end point is obvious and simple to obtain. However, with sinking feed determining the satiation end point is neither obvious nor simple. Feed rate adjustments may be done based on periodic sampling to determine the average and total weight of fish and then using a feeding table (such as Table VI-15) to determine the proper feed rate and allowance.

Techniques for feeding fish vary, but the most basic techniques for distributing feed into ponds include "sprinkling", "broadcasting" and mechanical. The sprinkling technique is the traditional method used in China. With this method each day's feed allowance is cast into the pond by the hand-handfuls over a 3 to 4 hour period in the morning and a similar period in the afternoon. The broadcasting technique requires that the feed allowance for each feeding be broadcast into the pond all at once. Mechanical feeders are either automatically set to distribute feed at timed intervals or to release feed upon stimuli by feeding fish. Neither sprinkling nor mechanical methods are recommended for feeding fish in ponds. Sprinkling might be considered if water stability of the feed is £ 5 minutes, but only feeds with water stability times 310 minutes are recommended.

A direct head-to-head trial was conducted in Heilongjiang, China (Jin Shan Bao Fish Farm, Harbin) to compare sprinkle and broadcast methods for raising common carp fry from <1 g fry to 3150 g fingerlings in ponds using 80:20 technology. The broadcast method, compared to the sprinkling method, gave an imperical 4% higher common carp yield (11,025 vs. 10,620 kg/ha) and 5% lower FCR (1.09 vs. 1.17), but 25% greater net profit (1,970 vs. 1,576 $/ha). The large difference in net profit was partially because of 600% greater labor cost (1,020 vs. 6,135 $/ha) where the sprinkling method was used. Common carp in the broadcast treatment were observed to grow more uniformly than carp in the sprinkling treatment, perhaps because sprinkling may favor the more aggressive fish.

On Farm Feed Handling and Storage

Feed quality will begin to steadily decline soon after its manufacture. The rate and magnitude of decline may be significantly slowed by proper feed handling and storage. The following are guidelines for handling and storing dry pelleted fish feeds from time of purchase.

1. Purchase feed as carefully and discriminately as you would fresh fish and vegetables at the market for your family. Obtain only recently manufactured feeds (pelleted within the past 4 weeks) that meet nutritional and physical standards. Purchase at one time only the amount of feed that will be used within 4 to 6 weeks.

2. During feed transport and handling, protect it from moisture, heat and direct sunlight.

3. Store feed in a cool, shaded, dry and ventilated location. White, wooden buildings with reflective metal roofs are excellent for storing feed. Heat and sunlight directly destroy feed nutrients. Warm, moist and stagnant air enhances mold growth and attracts insects. Do not stack bags of feed directly against a wall or on a concrete floor. Protect the feed from contact with rodents, chickens, and other animals. Try to minimize insect contact and infestation. If pesticides are used, prevent their direct contact with the feed.

4. Avoid feeding molded or spoiled feed as indicated by gray, blue or green color on the pellets; sour or musty, mildew odor; feed that has been wet; or clusters of fused pellets.