CHAPTER

Formulation of Aquafeeds

4

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Introduction

The development of a feed that is both effective and economical for an aquaculture species in all its life stages is a continuous effort. Aquafeed development started when natural food sources in culture systems became inadequate and had to be supplemented with prepared feed. As fish stocking densities in culture increase, supplemental feeding is no longer sufficient. A complete feed that contains all the necessary nutrients in sufficient amounts to bring about good growth, survival, and reproduction is needed. Feed ingredients generally come from animal or plant sources and some are by-products of the food industry. There is no single feed ingredient or feedstuff that contains all the nutrients in adequate amounts. Thus, different feed ingredients are combined to make a feed that has the desired composition and nutrient levels. In combining various feed ingredients, it is important to know how much of each feed ingredient should be used to produce a cost-effective aquafeed.

With the growth and expansion of aquaculture into a major industry, several fish species are being cultured; thus, the development of more efficient aquafeed formulations should continue. In developing cost-effective formulated diets, many important factors have to be considered. This chapter discusses these factors and the mathematical calculations in formulating a feed. It aims to enable students to formulate diets using purified and practical feed ingredients, and also to formulate effective supplemental and complete diets for aquaculture species.

Feed Ingredients for Aquaculture

Feed ingredients or feedstuffs for aquaculture come from many different sources and are used because oftentimes they are not utilized for human consumption. The choice of a feed ingredient in aquafeed formulation depends on: content of essential nutrients; digestibility and bioavailability; absence of antinutritional factors and toxic substances; commercial availability; and cost.

Animal and plant materials are the most common feed ingredients. Some wastes and by-products of the food industry are also utilized. There

Table 4.1 Some sources of protein, lipid, and carbohydrate in aquaculture feeds

Protein	Lipid	Carbohydrate
Blood meal	Beef tallow	Bread flour
Copra meal	Corn oil	Cassava starch
Defatted soybean meal	Cod liver oil	Corn meal
Fish meal	Coconut oil	Corn starch
Meat and bone meal	Cottonseed oil	Fine rice bran
Shrimp head meal	Menhaden oil	Sago palm starch
Shrimp meal	Pollack liver oil	Seaweeds
Squid meal	Tuna liver oil	
Trash fish	Squid liver oil	
Yeast	Soybean oil	

are feed ingredients that are indigenous in some areas and may not be available in commercial quantities. Some feed ingredients for aquaculture feeds are listed in Table 4.1 and shown in Figure 4.1.

Feedstuffs of animal origin usually contain high amounts of protein with good amino acid profile (Table 4.2). A protein source is considered good if the amino acid profile is close to that of the species being fed. Some plant protein sources have high protein content but they often have inferior amino acid profiles compared with protein from animal sources. Feedstuffs from plants are good sources of carbohydrate, and some are of good protein quality such as soybean meal. Some protein sources like legumes and nuts are also sources of energy but are more expensive than the common carbohydrate sources with high levels of digestible carbohydrate such as sago palm starch and bread flour. Generally, carbohydrates are cheaper sources of energy (Figure 4.2) than lipid or fat sources. They are also used as feed

Figure 4.1
Some feedstuffs for aquafeeds, fish offal (A) shrimp meal (B) animal meat waste (C) meat and bone meal (D) soybean meal (E) and yeast (F).

Table 4.2 Amino acid composition of some fish meals (FM), leaf meals (LM) and other protein sources

	Amount (g/100 g protein)											
Amino acid	White FM	Peruvian FM	Sapsap FM	Tuna FM	Tabagak FM	Shrimp meal	Squid meal	Soybean meal	Kangkong LM	Camote LM	Ipil-ipil LM	Acacia LM	Tamarind LM
Alanine	6.0	6.1	6.7	5.0	5.5	5.5	5.8	4.0	5.0	5.2	6.2	3.2	3.6
Arginine	6.2	5.5	4.0	5.4	4.7	7.1	7.5	6.0	3.3	3.7	5.2	2.2	2.4
Aspartic acid	9.4	8.7	9.5	8.5	8.1	8.3	10.1	11.1	8.7	10.2	11.4	6.3	7.6
Cystine	0.7	0.9	0.8	0.7	0.9	0.6	0.9	1.2	0.5	0.3	0.6	0.5	0.5
Glutamic acid	13.8	13.2	14.9	11.2	11.3	12.4	15.8	18.7	8.8	10.2	11.2	6.6	7.6
Glycine	7.0	5.4	6.4	5.2	5.3	4.9	5.7	4.0	4.3	4.7	6.0	3.2	4.0
Histidine	2.2	1.8	3.9	5.6	2.3	2.1	2.2	3.2	2.7	2.8	1.4	3.9	4.0
Isoleucine	3.9	4.1	4.5	3.9	4.2	3.8	4.2	4.5	3.4	3.7	6.6	2.4	3.0
Leucine	7.4	7.1	7.5	6.5	6.6	6.7	7.7	7.2	6.5	7.9	6.6	4.8	5.7
Lysine	7.7	7.4	7.3	6.2	7.3	6.3	7.8	5.8	4.6	4.4	6.1	2.9	3.4
Methionine	3.0	2.8	2.9	2.3	2.8	2.4	2.8	1.4	1.5	1.8	1.2	0.9	0.9
Phenylalanine	4.3	3.8	3.8	3.8	3.5	3.8	3.4	5.2	5.7	6.5	3.9	3.8	4.2
Proline	4.3	4.2	3.5	3.7	3.0	3.2	3.8	5.5	3.9	3.8	5.5	3.6	3.8
Serine	4.4	3.6	3.4	3.3	3.1	3.1	3.9	5.2	3.7	4.3	4.4	3.2	3.8
Threonine	4.2	3.9	3.9	3.6	3.7	3.6	4.1	3.8	3.9	4.4	5.1	2.7	3.6
Tryptophan	1.0	0.7	1.2	0.8	0.8	1.1	1.0	0.4	NA	NA	NA	NA	NA
Tyrosine	3.8	3.2	4.4	2.6	3.3	3.3	3.1	2.7	4.1	6.5	3.4	3.5	3.0
Valine	5.1	5.2	5.2	4.5	4.9	4.3	4.3	4.4	5.3	5.8	6.3	3.5	3.9
% Protein	70.5	70.5	66.0	77.2	78.4	71.8	78.7	43.8	31.9	30.8	27.8	25.3	15.1

Values given are means; NA, not analyzed
Source: Peñaflorida 1989

Figure 4.2
Some sources of dietary energy are corn (A), rice bran (B), cassava (C).

binders. Aside from carbohydrates, lipids are also used as sources of energy. They also provide essential fatty acids in fish diets. Examples of commonly used dietary lipid sources are fish liver oils and plant oils such as soybean oil and corn oil.

The choice of a feed ingredient is mainly dependent on the amount of essential nutrients that it contains. Table 4.3 gives the proximate composition (crude protein, crude fat, digestible carbohydrate or NFE, crude fiber, and ash) of some feed ingredients. Feedstuffs containing high amounts of protein with good amino acid profile are usually expensive and their use is constrained by cost. The bioavailability of nutrients present in a feedstuff varies for different aquaculture species and will influence the level of inclusion of a feedstuff in the feed formula. Although feedstuffs may contain the same amount of nutrient, for example protein, the feedstuff with more digestible protein should be chosen over that with

Table 4.3 **Proximate composition of some feed ingredients analyzed by the Centralized Analytical Laboratory at Southeast Asian Fisheries Development Center, Aquaculture Department ***

	Amount (% dry matter)					
	Moisture	Crude Protein	Crude Fat	Crude Fiber	NFE**	Ash
Animal:						
Fish meal (FM, local) (6)	10.3	64.1	6.5	0.8	8.5	20.1
FM, Chilean (27)	8.4	70.1	8.5	0.5	4.1	16.8
FM, Danish (2)	9.5	73.9	9.4	0.3	2.4	14.0
FM, Peruvian (30)	8.3	68.3	5.9	0.8	7.7	17.3
FM, Peruvian (26)	7.1	67.9	10.0	1.3	4.1	16.7
FM, tuna (9)	9.4	65.4	8.0	0.8	8.8	17.0
FM, white (11)	7.2	69.0	7.6	0.6	4.8	18.0
Prawn head meal (35)	6.5	51.2	5.2	13.3	5.3	25.0
Shrimp meal, *Acetes* sp. (60)	8.2	68.6	3.9	3.6	7.6	16.3
Squid meal (60)	6.9	78.5	5.5	1.3	6.7	8.0
Squid meal, scrap (4)	5.5	74.1	7.1	0.9	8.1	9.8
Frog meal (2)	7.6	62.5	1.7	1.2	4.7	29.9
Blood meal (2)	6.3	87.7	3.0	0.4	3.3	5.6
Meat and bone meal (19)	5.6	46.8	9.6	2.0	7.5	34.1
Plant:						
Acacia Leaf Meal (LM) (2)	4.4	25.7	5.6	21.2	41.7	5.8
Alfalfa LM	7.2	17.2	3.0	27.7	42.9	9.2
Camote LM, (7)	4.5	29.7	4.9	10.0	43.2	12.2
Cassava LM, (8)	5.9	22.1	9.3	12.4	49.2	7.0
Ipil-ipil LM, giant (14)	7.8	25.1	6.8	10.6	44.0	13.5
Ipil-ipil LM, native (6)	10.3	29.3	8.8	11.5	43.5	6.9
Kang-kong LM (6)	5.7	28.5	5.4	10.5	43.6	12.0
Malunggay LM (7)	3.5	30.4	8.4	8.3	43.7	9.2
Papaya LM (10)	5.4	20.7	11.6	11.2	42.6	13.9
Copra meal (10)	7.9	22.0	6.7	17.3	44.3	9.7
Cowpea (7)	8.0	23.0	1.3	4.1	67.5	4.1
Cowpea, dehulled (2)	7.7	25.4	0.9	1.4	68.3	4.0
Mungbean, green (5)	7.1	23.2	1.2	3.1	68.7	3.8
Mungbean, yellow (5)	7.7	24.1	1.1	3.8	67.1	3.9
Rice bean (2)	5.0	26.5	0.8	4.0	64.6	4.1
Corn meal (10)	8.4	7.8	4.7	2.6	83.1	1.8
Cornstarch (5)	11.9	0.4	0.2	1.1	98.2	0.1
Flour, bread (40)	12.1	12.9	1.2	0.3	84.9	0.7
Flour, whole wheat (15)	11.3	15.3	1.7	0.8	81.1	1.1
Wheat, Pollard (4)	9.5	15.4	4.5	10.3	64.0	5.8
Germ, wheat (2)	6.0	27.8	4.3	3.4	59.6	4.9
Gluten, corn (5)	7.3	62.6	7.7	2.2	25.9	1.6
Gluten, wheat (6)	8.9	80.7	1.4	0.4	16.4	1.1
Rice bran (78)	9.2	13.3	14.1	8.5	53.4	10.7
Rice bran, tiki-tiki (5)	10.7	18.0	2.0	8.0	62.4	9.6
Rice hull (7)	7.0	3.3	2.0	32.4	41.6	20.7
Soybean meal, as is (21)	5.6	35.8	19.8	4.9	33.9	5.6
Soybean meal, defatted (108)	8.4	43.6	1.5	5.5	41.7	7.7
Other sources:						
Casein (11)	7.2	89.7	0.1	0.3	8.9	1.0
Crab meal (2)	4.2	37.9	4.1	10.7	8.9	38.4
Gelatin (6)	7.9	94.4	0.0	0.1	5.1	0.4
Mussel meal, green (30)	5.9	64.6	8.6	3.0	12.5	11.8
Oyster meal (6)	4.4	54.6	9.4	4.0	20.1	11.9
Scallop meal (2)	7.3	65.2	10.9	1.4	8.8	13.7
Snail meal, kuhol (5)	4.0	52.1	1.8	2.1	15.7	28.3
Yeast, Brewers (2)	7.2	49.4	1.6	2.4	34.5	12.1

Table 4.3 *(contiunued)*

	Amount (% dry matter)					
	Moisture	Crude Protein	Crude Fat	Crude Fiber	NFE* **	Ash
Yeast, *Candida* (3)	8.3	55.2	0.8	1.7	35.1	7.4
Natural Food:						
Acartia sp. (copepods)	7.8	71.2	8.3	5.4	9.9	5.2
Artemia (37)	8.0	55.5	6.8	11.3	15.0	11.4
Azolla (2)	8.0	27.2	3.4	12.9	36.5	20.0
Brachionus sp.(5)	8.1	51.9	10.4	3.5	15.3	18.9
Chaetoceros calcitrans (7)	7.6	24.4	7.1	2.5	26.7	39.3
Chlorella, marine (3)	10.1	35.1	4.2	5.6	27.7	27.4
Isochrysis galbana (2)	10.4	33.6	18.1	4.4	23.0	20.9
Moina macrocopa (3)	8.5	57.8	7.6	8.4	17.2	9.0
Sargassum (2)	10.4	9.0	0.8	9.6	46.4	34.2
Skeletonema sp. (4)	10.4	24.7	2.6	0.7	20.2	51.8
Spirulina (2)	8.0	56.7	2.8	0.6	28.1	11.8
Tetraselmis sp. (4)	5.5	49.1	10.7	2.1	19.0	19.1
Digman (4)	9.8	20.6	3.3	16.4	35.9	23.8
Enteromorpha (lumot) (15)	15.2	13.8	1.9	9.3	36.9	38.1
Gracilaria sp. (18)	7.0	10.2	0.4	5.8	44.8	38.8
Kappaphycus sp. (10)	6.1	5.4	0.8	6.1	57.3	30.4

* Values are means for the number of samples given in parentheses. Not all feed ingredients are available in commercial quantities but may be used where they are commonly found in large amounts.
**NFE - Nitrogen-free extract

poor protein availability. The digestibility of protein (expressed in percentage) in some feedstuffs for some aquaculture species are listed in Table 4.4.

Table 4.4 Apparent protein digestibility coefficients (APDC) in % of some feedstuffs for aquaculture species

Aquaculture Species	Feedstuffs	APDC %	References
Shrimp			
Tiger shrimp	Fish meal	61	Catacutan 1997
	Soybean meal, defatted	93	"
	Squid meal	96	"
	Shrimp meal	95	"
	Shrimp head meal	89	"
	Meat and bone meal	74	"
	Yeast Candida sp.	93	"
	Copra meal	75	"
Fish			
Milkfish	Fish meal	45-81*	Ferraris et al. 1986
	Defatted soybean meal	45-94*	"
Carp	White fish meal, mechanical extracted	95	NRC 1977
	Soybean seed meal, solvent extracted	81-96	"
Red sea bream	White fish meal, mechanical extracted	61-87	"
Channel catfish	Soybean seed meal, solvent extracted	72-84	"

* tested at different salinities

Many other components are added in the feed formula aside from the major sources of nutrients. In complete feed formulations, micronutrients are added in small amounts in the form of vitamin and mineral mixtures. Examples of these mixes for crustaceans and fishes are shown in Tables 4.5, 4.6, and 4.7. For economic reasons, other substances are also

Table 4.5 Vitamin and mineral mixtures for crustaceans (A) and tiger shrimp juvenile (B).

	mg/100 g dry diet	
	A*	B**
Thiamine HCl (B_1)	1.26	4.0
Pyridoxine HCl (B_2)	3.70	12.0
Riboflavin (B_6)	2.57	8.0
Cyanocobalamin (B_{12})	0.025	0.08
Nicotinic acid	12.62	40.0
Folic acid	0.25	0.8
Biotin	0.13	0.4
Para aminobenzoic acid	3.16	10.0
Calcium pantothenate	18.93	60.0
Inositol	126.18	400.0
Na-ascorbate (C)	630.92	2000.0
Choline chloride	189.27	600.0
β-carotene (A)	3.03	9.6
Calciferol (D)	0.38	1.2
α-tocopherol (E)	6.31	20.0
Menadione (K)	1.26	4.0
TOTAL	1000.00	3170.08
MINERALS	g/100 g dry diet	
	A*	B**
K_2HPO_4	2.339	2.000
$Ca_3(PO_4)_2$	3.181	2.720
$MgSO_4.7H_2O$	3.556	3.041
$NaH_2PO_4.2H_2O$	0.924	0.790
TOTAL	10.000	8.551

* *Source:* Teshima and Kanazawa 1982

included in the feed formula to reduce fines during feed manufacture, and storage losses due to feed degradation and spoilage, and improve feed durability during handling and water stability. These substances include synthetic binders, antioxidants, and mold inhibitors. To make feed more attractive to fish, pigments and attractants may be added (Table 4.8).

Feed Formulation

Feed formulation is a process that involves combining various feed ingredients, which contain different amounts of nutrients, so that the resulting composition would meet the specific requirement of the cultured species. The nutrient levels of feed ingredients to be used are balanced mathematically in order to come up with the desired final composition.

Table 4.6 Recommended vitamin mixture for warmwater fishes such as milkfish, sea bass, and catfish *

Vitamin	Amount (per kg) in dry diet[a]	
	Supplemental	Complete
Vitamin A activity	2,000 IU	5,500 IU
Vitamin D_3 activity	220 IU	1,000 IU
Vitamin E	11 IU	50 IU
Vitamin K	5 mg	10 mg
Choline	440 mg	550 mg
Niacin	17-28[b] mg	100 mg
Riboflavin	2-7[b] mg	20 mg
Pyridoxine	11 mg	20 mg
Thiamin	0	20 mg
Calcium pantothenate	7-11[b] mg	50 mg
Biotin	0	0.1 mg
Folacin	0	5 mg
Vitamin B_{12}	2-10 mg	20 mg
Ascorbic acid	0-100[b] mg	30-100[b] mg
Inositol	0	100 mg

[a] These amounts do not allow for processing or storage losses.
[b] Highest amounts are appropriate when "standing crop" of fish exceeds 500 kg/hectare.
* *Source:* NRC 1977.

Table 4.7 Mineral mixtures for purified and practical warmwater fish diets*

Mineral	Dry Diet (g/100g)
Practical Diets	
$CaCO_3$	0.750
$MnSO_4.H_2O$	0.030
$ZnSO_4.7H_2O$	0.070
$CuSO_4.5H_2O$	0.006
$FeSO_4.7H_2O$	0.050
NaCl	0.750
KIO_3	0.0002
$CaHPO_4.2H_2O$	2.00
Purified Diets	
$CaHPO_4.2H_2O$	2.07
$CaCO_3$	1.48
KH_2PO_4	1.00
KCl	0.10
NaCl	0.60
$MnSO_4.H_2O$	0.035
$FeSO_4.7H_2O$	0.05
$MgSO_4$	0.30
KIO_3	0.001
$CuSO_4.5H_2O$	0.003
$ZnCO_3$	0.015
$CoCl_2$	0.00017
$NaMoO_4.2H_2O$	0.00083
Na_2SeO_3	0.00002

Source: NRC 1977

Table 4.8 Other feed additives

Feed Binders
- agar
- alginic acid
- α starch
- bentonites
- carboxymethy cellulose (CMC)
- carrageenan
- gelatin
- gracilaria (dried and ground)
- hemicellulose
- lignosulfates

Antioxidants
- vitamin C
- butylated hydroxyanisole (BHA)
- butylated hydroxytoluene (BHT)
- ethoxyquin (1,2 dihydro-6-ethoxy, -2,2,4-trimethylquinoline)

Mold inhibitors
- citric acid
- sodium, calcium, or potassium sorbate

Attractants:

Color
- carotenoids
- xanthoterin (red and yellow xanthophylls)

Feed:
- betaine
- glutamic acid
- taurine

It also takes into account the cost of materials, acceptability, and ease of preparation.

The two most important factors to consider in formulating a feed for any aquaculture species are nutrient requirements and feeding behavior. Other factors to consider are the stages in the life cycle (larval, grow-out or broodstock) and the type of culture system. Like any other animal, fish and crustaceans need enough protein, lipid, energy, vitamins, and minerals. These nutrients should be present in the formulated feed in adequate amounts. Excessive amounts of nutrients is wasteful, while insufficient levels will result in slow growth. An allowance is made in the formula for nutrient losses during feed manufacture.

The feeding habit and behavior of the animal is also an important aspect to consider in feed formulation. For example, crustaceans such as shrimps and crabs are slow eaters and they take some time to consume the pelleted feed. In contrast, fish consume the feed immediately and, oftentimes, the feed is eaten before it touches the pond bottom. Thus, crustaceans require a more water stable feed than fish. A feed binder, usually a carbohydrate source, is added to the formulation to make the pelleted feed stay intact much longer in the water. Seaweed extracts such as kappa-carrageenan and alginates are commonly used as binders in microbound larval diet preparation. Larval diets may be prepared in suspension form, colloid form, in solution, or in dry form enclosed within a microcapsule or microcoated with a binder. Sometimes an attractant is added to the feed so that the pellet can easily be located and quickly consumed by the fish. Most aquatic species in the larval stage stay in the water column and gradually become bottom dwellers. Thus, the preferred feed at the early life stages is a feed that does not settle in the tank bottom but stays in the water column for a long time. Some aquatic species may prefer a specific feed form, type, or size that should be considered in feed formulation.

The requirement for nutrients and energy varies for broodstock, grow out, and larval stages; therefore, feed formulation would also vary in nutrient content depending on the growth stages. Although feed has been formulated and tested for all the life stages of milkfish, tilapia, and shrimp and for various stages in some species (see Chapter 7), these are continuously being refined based on recent research findings. Recent data on nutrient requirements, and availability of new, cheap but good protein sources are important information in refining a feed formula.

The processed feed is influenced by the quality of the feed ingredients. Some feedstuffs show wide fluctuations in their nutrient content due to seasonal and geographical variations. Feedstuffs should first be analyzed for their proximate composition, but if this is not possible, feed composition tables (FCT) can be used as guide in formulating feeds. In some FCTs, the moisture content is included and the amounts of nutrients are expressed either on a dry matter basis or on as received basis. In formulating feeds, a uniform set of values should be consistently used. Values are expressed either on a dry matter basis, or as received basis. To convert the amount of nutrients from dry matter basis to as received basis, use the formula:

$$\%\ \text{nutrient (as received)} = \%\ \text{nutrient (dry matter basis)} \times \frac{(100 - \%\ \text{moisture})}{100}$$

There is no definite feed formula for any species because of the many environmental and physiological factors involved as well as differences in the availability of feed ingredients from one locality to another. Substitution of a feedstuff or feedstuffs in the formula is possible provided that the final formulation is similar in nutrient content and there are no negative effects on growth and survival and increase in feed cost. Feeding experiments have shown that favorable results are obtained as long as the amounts of nutrients present do not exceed the recommended nutrient levels. Excess of nutrients can be expensive, and can cause deterioration of the culture system. Maximum levels of incorporation of some feedstuffs in the formula for carnivores, omnivores, and herbivores are listed in Table 4.9

Table 4.9 **Recommended maximum inclusion levels (%) of some major feed ingredients in a practical diet for fish and shrimp**

Feedstuffs	Fish		Shrimp	
	Carnivore	Omnivore/ Herbivore	Carnivore	Omnivore/ Herbivore
Alfalfa meal	5	10	5	10
Blood meal, spray dried	10	10	10	10
Cassava/Tapioca meal	15	35	15	25
Coconut meal	15	25	15	25
Corn grain meal	20	35	15	
Corn gluten meal	15	20	15	20
Cottonseed meal, solvent extracted	15	20	10	15
Corn distillers	10	15	10	15
Dicalcium phosphate	3	3	3	3
Hydrolyzed feather meal	10	10	10	10
Fish meal	no limit	no limit	20	35
Fish protein concentrate	15	10	15	15
Ground meal, solvent extracted	15	25	15	25
Liver meal	50	50	25	20
Meat and bone meal,	20	25	15	20
Poultry by-product meal	15	20	15	20
Rapeseed meal, solvent extracted	20	25	15	20
Rice bran, solvent extracted	15	35	15	35
Shrimp meal	25	25	no limit	no limit
Squid meal	no limit	no limit	no limit	no limit
Sorghum meal	20	35	15	35
Soybean meal, solvent extracted	25	35	20	30
Soybean meal, full fat	35	40	20	30
Wheat grain meal	20	35	20	35
Wheat bran	15	30	15	30
Wheat gluten meal	15	15	20	20
Wheat middlings	25	40	20	35
Whey	10	10	10	10
Yeast (Brewers), dried	15	15	15	15

Source: Tacon 1988

There are several methods of formulating feeds. These are Pearson's Square Method, Algebraic Equation, Trial and Error, and Linear Programming. The Pearson's Square method is recommended in formulating a supplemental feed with only two to four ingredients. The Trial and Error method is generally used in calculating a formula for a complete diet with many ingredients. In commercial feed production where cost is a principal consideration, a computer program (Linear Programming) is used to combine feed ingredients that will give an effective formulation with the lowest cost.

Mathematical calculations using these methods, except for Linear Programming, are given in the following examples.

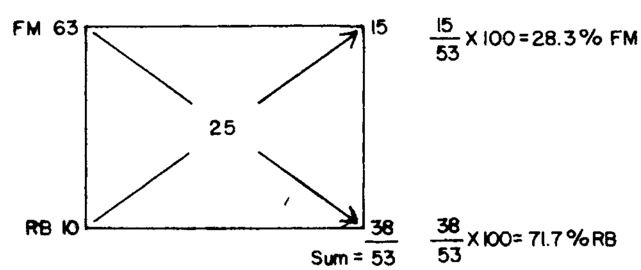
I. Pearson's Square and Algebraic Equation Methods

Example 1. When only two feed ingredients are to be combined.

To determine the amount of each ingredient in a supplemental feed that would contain 25% protein using Fish Meal (FM) and Rice Bran (RB), with protein contents of 63% and 10%, respectively.

❑ Pearson's Square Method:

a) First draw a square and write the desired protein level of the feed at the center of the square.
b) Write the two ingredients with their respective protein contents on each corner of the left side of the square, the ingredient with higher protein on the upper and with lower protein on the lower left hand corner.
c) Subtract the desired level of protein from each ingredient and write the difference on the right corner of the square that is diagonally opposite the protein level of each ingredient.
d) Get the sum of the numbers at the right side of the square.
e) Determine the percentage of each ingredient needed for the feed formula by dividing the numbers written on the right hand side by the sum of the difference multiplied by 100.



About 283 g FM and 717 g of RB are required to make a kg of the supplemental feed that will contain 25% protein. To check for the amount of protein in the feed, the protein content (in percent) of each ingredient is multiplied by the amount of FM and RB (283 g and 717 g respectively) to be combined. The amount of protein coming from each ingredient is added to get the total amount. The total amount is divided by 1000 and multiplied by 100 to give 25% protein.

FM	=	283 g x 63%	=	178.3 g protein
RB	=	717 g x 10%	=	71.7 g protein
		Total protein		250.0 g /kg or 25% protein

or (250 / 1000) x 100 = 25%

❑ **Algebraic Equation Method:**

Let: x = g FM/ kg feed
y = g RB/ kg feed

so that :

$$x + y = 1000 \text{ g feed} \quad \text{(Equation I)}$$
$$0.63\,x + 0.10\,y = 250 \text{ g protein/1000 g feed} \quad \text{(Equation II)}$$

Multiply Equation I by 0.10:

$$0.10\,x + 0.10\,y = 100 \text{ g} \quad \text{(Equation III)}$$

Subtract Equation III from Equation II:

$$\begin{array}{rl} 0.63\,x + 0.10\,y & = 250 \text{ g protein/1000 g feed} \\ -\,(0.10\,x + 0.10\,y & = 100 \text{ g}) \\ \hline 0.53\,x + \quad 0 & = 150 \\ x & = 150/0.53 = 283 \text{ g FM} \end{array}$$

Substitute in Equation I:

$$\begin{array}{rl} 283 + y & = 1000 \\ y & = 1000 - 283 = 717 \text{ g RB} \end{array}$$

Example 2: When three or more feed ingredients are available for use.

Formulate a fish diet to contain 35% protein by combining the following ingredients with their respective protein content:

FM	-	60% protein
Soybean Meal (SBM)`	-	45% protein
RB	-	8% protein
Corn Meal (CM)	-	12% protein

Assume the proportion of 1 part FM to 2 parts SBM or 1:2 and equal parts of RB and CM or 1:1. FM and SBM are the main sources of protein while RB and CM are the main sources of carbohydrate or energy but also contain protein.

❑ Pearson's Square Method:

a) Draw a square and write at the center the desired protein level as in the first example.

b) Calculate the protein level from the protein sources FM and SBM, according to the specified ratio: 1:2

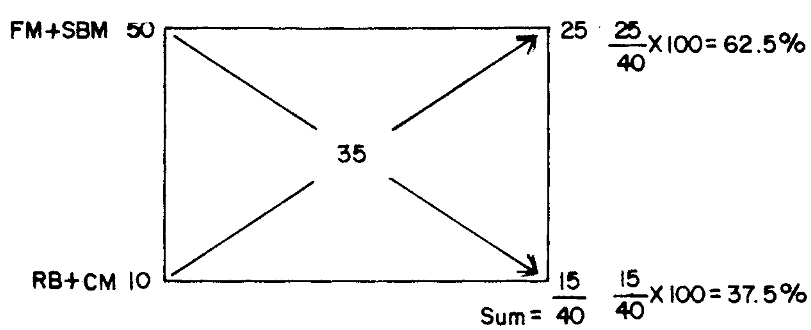
FM	:	1 x 60 =	60
SBM	:	2 x 45 =	90
Average	:		150 / 3 = 50

c) Calculate the energy sources, RB and CM also according to the ratio 1:1

RB	:	1 x 8 =	8
CM	:	1 x 12 =	12
Average	:		20 / 2 = 10

d) Write the calculated average protein content on the upper left hand corner for the protein sources and the protein content of the energy sources on the lower left corner of the square.

e) Write the desired protein level at the center and substract this value from the protein content of FM and SBM and protein content of RB and CM. Write the number diagonally opposite the ingredients or on the lower right hand corner for protein sources and upper right hand corner for energy sources. Proceed as in d) and e) of Example 1.



f) Multiply the final percentage derived for the protein sources by 1/3 for FM and 2/3 for SBM. For the energy sources, multiply by 1/2 each of the RB and CM to find out the exact amount of each ingredient to be used in the formula with the desired level of 35% protein.

Protein sources = 62.5%

			In %	In g/kg feed
FM	=	62.5 x 1/3	= 20.83%	208.3
SBM	=	62.5 x 2/3	= 41.67%	416.7

Energy sources = 37.5%

			In %	In g/kg feed
RB	=	37.5% x 1/2	= 18.75%	187.5
CM	=	37.5% x 1/2	= 18.75%	187.5
Total			100.00%	1,000

g) To check that a kilo of feed contains 35% protein, proceed as follows:

FM	=	208.3 g x 60% protein	=	125.0 g protein
SBM	=	416.7 g x 45% protein	=	187.5 g protein
RB	=	187.5 g x 8% protein	=	15.0 g protein
CM	=	187.5 g x 12% protein	=	22.5 g protein
Total per 1000 g feed				350.0 g protein/kg or 35%

❑ Algebraic Equation Method:

Separate ingredients into protein and energy sources and calculate average protein contribution of each group according to specified proportions as in Example 2 letters a), b) and c) Pearson's Square method. Then:

Let: x = g of FM and SBM of protein sources/ kg feed
y = g of RB and CM as energy sources/ kg feed

$$x + y = 1000 \text{ g feed} \quad \text{(Equation I)}$$
$$0.50\,x + 0.10\,y = 350 \text{ g protein/ kg feed} \quad \text{(Equation II)}$$

Multiply (I) by 0.10 : $0.10\,x + 0.10\,y = 100$ (Equation III)

Subtract (III) from (II):

$$\begin{aligned} 0.50\,x + 0.10\,y &= 350 \\ -(0.10\,x + 0.10\,y &= 100) \\ \hline 0.40\,x + 0 &= 250 \\ x &= 625 \end{aligned}$$

FM : 625 x 1/3 = 208.3 g
SBM : 625 x 2/3 = 416.7 g

From Equation (I):

y = 1000 – x
y = 1000 – 625 = 375

RB = 375/2 = 187.5 g
CM = 375/2 = 187.5 g

Example 3: When some feed components are fixed.

Prepare a fish diet to contain 32 % protein using FM (60% protein) and Copra meal or CpM (20% protein) as protein sources to be included in the diet:

Rice bran (10% protein)	=	22%
Mineral mix	=	2%
Vitamin mix	=	1%

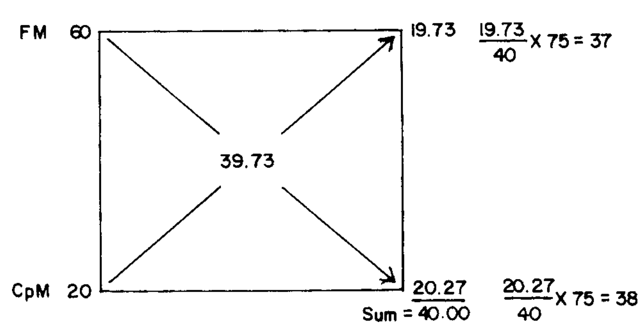
❑ **Pearson's Square Method:**

a) Determine the amount of FM and CpM per 1 kg feed mixture, by subtracting the amounts of RB, mineral mix and vitamin mix from 1000.
1000 - (220 + 20 + 10) = 750 g/ kg feed

b) Vitamin and mineral mixes do not contain protein, but 220 g RB supplies 22 g protein. Therefore, subtracting 22 g protein from RB from the 320 g desired protein level equals 298 g protein, which must come from 750 g of FM and CpM.

c) Convert to percentage the amount of protein (298 g/kg) and solve by the Pearson's Square method the amount that should come from the combined levels of FM and CpM (750 g):
298/750 x 100 = 39.73%

d) Follow steps a) to e) in Example 1 and check for final protein in one kg diet:



e) A total of 370 g FM (222 g protein) and 380 g CpM (76 g protein) gives 298 kg protein. This amount of protein plus the 22 g protein from 220 g RB makes a total of 320 g protein or 32% of one kg diet.

❑ Algebraic Equation Method:

Before proceeding to formulate the necessary equations, first do steps a) and b) described in the Pearson's Square method.

Let : x = g of FM required
y = g of CpM required

$$x + y = 750 \text{ g} \quad \text{(Equation I)}$$
$$0.60\,x + 0.20\,y = 298 \text{ g protein} \quad \text{(Equation II)}$$

Multiply (I) by 0.2 :

$$0.20\,x + 0.2\,y = 150 \quad \text{(Equation III)}$$

Subtract (III) from (II):

$$\begin{array}{rl} 0.60\,x + 0.20\,y & = 298 \\ -\,(0.20\,x + 0.2\,y & = 150) \\ \hline 0.40\,x + 0 & = 148 \\ x & = 148 / 0.4 = 370\text{g FM} \end{array}$$

Substitute (I):

$$370 + y = 750 \text{ g}$$
$$y = 380 \text{ g CpM}$$

II. Trial and Error Method

For the Trial and Error method, a worksheet and a table of proximate composition are necessary.

Example 1: Formulate a diet that will contain fish meal (FM), defatted soybean meal (DSBM), meat and bone meal (MBM), rice bran (RB), and vitamin and mineral mixes. Cod liver oil (CLO) is the lipid source, bread flour (BF) is the source of carbohydrate and binder, and lime is used as filler. The finished diet should contain 35% crude protein, 12% crude fat, with a dietary energy of 340 to 400 kcal/100 g diet.

The proximate composition of these feed ingredients are:

Ingredients	g/100 g				
	Protein	Fat	Fiber	Ash	NFE
FM	66.70	9.11	0.59	13.36	10.24
DSBM	50.34	1.45	8.59	7.64	31.98
MBM	46.91	10.90	1.11	36.10	4.98
RB	14.80	12.66	4.17	8.92	59.45
BF	14.17	1.54	0.56	0.68	83.05

The following ingredients are incorporated in fixed amounts:

FM	=	10%
SBM	=	18%
BF	=	5%
Vit/min mix	=	3%
Total	=	36%

The remaining percentage, which is 64%, will be supplied by MBM, RB, CLO, and the filler (lime). About 58 g will come from MBM and RB and 6 g from lipid and filler. The closest estimates to the required values are obtained by trial and error.

1. Fill in the required ingredients and the corresponding amounts in Columns 1 and 2 in the Worksheet (Appendix A).

2. Fill in the respective nutrient content based on the proximate composition of each ingredient on the upper left hand corner of each box (Worksheet 1).

3. Calculate the amount of nutrient from each ingredient by multiplying the specified amount of the ingredient (column 2) by the percentages of the nutrient (column 3) to obtain the amount in grams. Start with the protein sources.

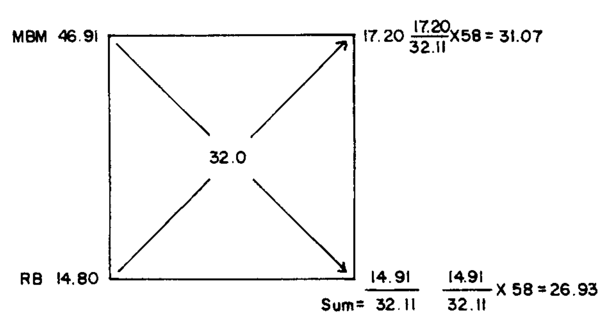
   For example, 10 g FM with 66.7% protein contributes 6.67 g protein to the diet. Add up the protein from FM, SBM, and BF (Worksheet 1, column 3). Do the same for the rest.

4. Calculate the amount of protein that should come from MBM and RB by subtracting the known protein contribution of the other ingredients (FM+DSBM+BF) from the total protein required (35%).

   35 g protein – (6.67 + 9.06 + 0.71) = 18.56 g protein to come from MBM +RB

   This value should come from 58 g of MBM + RB, which is 18.56/ 58 = 32% protein

5. Use Pearson's Square to calculate the exact amount of MBM and RB to be used in the feed formulation:



6. Fill-up Worksheet 2 with calculated amounts of MBM (31.07 g) and RB (26.93 g).

7. Calculate nutrient contribution from each feed ingredient. After the amounts of protein sources have been calculated, proceed to calculate the lipid sources and lipid levels.

   For lipids, the partial amount from other ingredients is equal to 8.05%, therefore, to meet the requirement of 12%, CLO will be added at 3.95% (column 4). To make the formulation 100%, calculate all the other nutrients and determine how much filler or lime to add by subtracting 97.95 from 100 equals 2.05.

8. Calculate the sum of fiber, ash and NFE to have a complete record of the major nutrients. Indicate these values in columns 5, 6, and 7, respectively. These can be compared to the analyzed proximate composition of processed feed.

9. To determine the dietary energy/100 g diet use the physiological values of 4.5, 8, 3.3 as follows:

Protein	= 35 g	x	4.5 kcal/g	=	157.5 kcal
Fat	= 12 g	x	8.0 kcal/g	=	96 kcal
Carbohydrate	= 28.5 g	x	3.3 kcal/g	=	94 kcal
					347.5 kcal/100 g diet

Worksheet 1

Calculated nutrient composition of feed

Feed formulation code: M-1

Date computed: March 8, 2000

Formulated by: Mary Cruz

Ingredients (1)	g/100g (2)	Protein% (3)	Fat% (4)	Fiber% (5)	Ash% (6)	NFE% (7)
Fish Meal	10	66.7 6.67	9.11	0.59	13.36	10.24
Meat and Bone Meal						
Soybean meal (defatted)	18	50.34 9.06	1.45	8.59	7.64	31.98
Rice bran						
Bread flour	5	14.71 0.71	1.54	0.56	0.68	83.05
Vitamin/mineral mix	3					
Cod liver oil						
Lime						
		35.00 − 16.44 18.56				
TOTAL	36					

Worksheet 2
Calculated nutrient composition of feed

Feed formulation code: M-1
Date computed: March 8, 2000
Formulated by: Mary Cruz

Ingredients (1)	g/100g (2)	Protein% (3)	Fat% (4)	Fiber% (5)	Ash% (6)	NFE% (7)
Fish Meal	10	66.70 6.67	9.11 0.91	.59 0.06	13.36 1.34	10.24 1.02
Meat and Bone Meal	31.07	46.91 14.57	10.90 3.39	1.11 3.34	36.1 11.22	4.98 1.55
Soybean meal (defatted)	18	50.34 9.06	1.45 0.26	8.59 1.55	7.64 1.38	31.98 5.76
Rice bran	26.93	14.8 3.98	12.66 3.41	4.17 1.12	8.92 2.40	59.45 16.01
Bread flour	5	14.17 0.71	1.54 0.08	0.56 0.03	0.68 0.03	83.05 4.15
Vitamin/mineral mix	3					
Cod liver oil	3.95		100 3.95			
Lime	2.05				100	
TOTAL	100	35.0	12			

Example 2: Formulate a diet that would contain not less than 40% protein with dietary energy content of not less than 340 kcal/100 g diet with the following feed ingredients. Consider also the digestibility coefficients of the major nutrients, protein, lipid, and carbohydrate

Use FM and SM in a 1:1 ratio
Lipid source is cod liver oil, with total dietary fat not to exceed 15%
Carbohydrate source is bread flour
Vitamin mix 2%, Mineral mix 1%, and Lecithin 0.5%
Filler is cellulose

The proximate analysis and digestibility coefficients of protein, lipid, and carbohydrate sources on a dry matter basis:

	% Nutrients					% Digestibility		
	Protein	Lipid	Carbo-hydrate	Crude fiber	Crude ssh	Protein	Lipid	Carbo-hydrate
Fish meal	65.8	5.9	7.8	0.8	19.7	80	93	94
Shrimp meal	68.6	3.7	7.5	3.6	16.6	75	96	97
Squid meal	78.5	5.5	6.8	1.2	8.0	88	91	89
Bread flour	13.9	1.2	83.9	0.3	0.7	75	90	95

The fixed amount from vitamin and mineral mixes and lecithin, is 3.5%. The remaining amount is equal to 96.5% and will be supplied by the other ingredients. In Worksheet 3:

1. Fill in the fix ingredients and the corresponding amounts in Worksheet 3. Then, try a 1:1 ratio of 25 g each of FM and SM and write these numbers on the worksheet.

2. Fill in the nutrient composition of FM and SM in Worksheet 3, columns 3 to 7 on the left hand box for each column corresponding to each nutrient. Calculate the nutrient contribution based on the proximate composition and digestibility coefficients and fill in the respective box.
   Compute the protein, lipid, and carbohydrate contributed by a feedstuff using the formula:

$$\text{Weight of feedstuff} \times \frac{\%\ \text{Protein}}{100} \times \frac{\%\ \text{Digestibility}}{100}$$

From the proximate composition table,

FM: 25 g x 0.658 x 0.80 = 13.16 g protein
25 g x 0.059 x 0.93 = 1.37 g lipid
25 g x 0.078 x 0.94 = 1.83 g carbohydrate

Do the same for SM.

3. Calculate the amount of protein to be contributed by SqM as:

13.6 g (FM) + 12.7 g (SM) = 26.3 g

40g (total protein) – 26.3g (FM + SM) = 13.7 g SqM protein

To calculate weight of SqM to be used in the formula:

$$\text{Weight of SqM} = \left(\frac{\text{SqM protein}}{\%\text{Protein}/100}\right) \times \left(\frac{\%\ \text{Digestibility}}{100}\right)$$

$$= \frac{13.7\ \text{g}}{(0.785 \times 0.88)} = 19.8\ \text{g SqM}$$

4. Fill in the calculated amounts of protein, lipid, and carbohydrate from 19.8 g SqM (using the formula in step 2).

5. Sum up the dietary lipid from all the protein sources and subtract the value to calculate the amount of CLO to be added. Assume dietary lipid to be about 12% [12 – (1.37 + 0.89 + 0.99) = 8.75].

6. Sum up the dietary energy (use energy values for each nutrient in the previous example) at this point to be able to calculate the amount of energy to be contributed by bread flour (340 kcal – 292.5 kcal = 47.5 kcal):

Protein	: 40 g x 4.5 kcal/g	=	180
Lipid	: 12 g x 8.0 kcal/g	=	96
NFE	: 5 g x 3.3 kcal/g	=	16.3
			292.5 kcal

7. Bread flour is about 90% carbohydrate with a digestibility of about 95%, so that 47.5 kcal divided be 3.3 is about 14.4 g. Since the digestibility is less than 100%, the amount of bread flour maybe increased to 16 g. Calculate the nutrients contributed by 16 g bread flour (as in step 2).

8. Determine the sum of ingredients used (25+25+19.8+16+3+0.5+8.75 = 98.05) and subtract the value from 100. The difference is the amount of the filler, cellulose (1.95) to make the total equal to 100.

9. Add up the nutrients and calculate the total dietary energy /100g diet.

Protein	: 41.5 g x 4.5 kcal/g	=	186.8
Lipid	: 12.67 g x 8.0 kcal/g	=	101.4
Carbohydrate	: 17.83 g x 3.3 kcal/g	=	58.8
			347.8 kcal/100g

10. Compute the total ash and fiber content in the feed formula (column 5 and 6). The minimum dietary level for ash or fiber is about 10% because higher levels can cause poor growth and survival. Compare the computed values to the actual results of the chemical analysis to detect discrepancies.

Worksheet 3
Calculated nutrient composition of feed

Feed formulation code: M-1
Date computed: March 10, 2001
Formulated by: Mary Cruz

Ingredients (1)	g/100g (2)	Protein% (3)	Fat% (4)	Fiber% (5)	Ash% (6)	NFE% (7)
Fish Meal	25	65.8 13.2	5.9 1.37	0.8 0.20	19.7 4.92	7.8 1.83
Shrimp meal	25	68.6 12.9	3.7 0.89	3.6 0.90	16.6 4.15	7.5 2.0
Squid meal	19.8	78.5 13.7	5.5 0.99	1.2 0.24	8.0 1.58	6.8 1.2
Bread flour	16.0	13.9 1.7	1.2 0.17	0.3 0.05	0.7 0.11	83.9 12.8
Vitamin/mineral mix	3.0					
Lecithin	0.5		100 0.5			
Cod liver oil	8.75		100 7.5			
Cellulose	1.95					
TOTAL	100	41.5	12.67	1.39	10.76	17.83

III. Linear Program for Least-Cost Formulation

Linear programming is used when many ingredients are to be combined for a least cost feed formula. This method is especially useful in commercial feed manufacture wherein large quantities of feed ingredients are used. A computer is necessary in this type of formulation. When one or more ingredients are not available, other feed ingredients are utilized as substitutes in order to come up with the same feed quality. The quantities of substitute ingredients are determined using the linear programming method. Information on the amounts of nutrients in each of the feed ingredients to be used is essential in this method. This can be obtained from a feed composition table or chemical analysis. A computer program will list several combinations to come up with almost similar feed quality at a lesser cost. Examples of computer program for least cost formulation are the simple linear programming spreadsheet and the sophisticated Brill Formulation Package.

Purified Diet Formulation

In nutritional requirement studies, purified ingredients are used in the formulation of diets. This is necessary to study the optimum level of one specific nutrient, e.g. essential amino acid. The use of purified ingredients enables one to vary the level of the nutrient whose dietary requirement is being studied while keeping the other nutrient levels constant. Examples of purified ingredients include casein and gelatin as protein sources, dextrin and sucrose as carbohydrate sources, and cellulose for the non-nutritive filler.

Example: Formulate a purified diet to contain about 50% protein using casein and gelatin at 1:1 ratio, cod liver oil level at 12%. and vitamin and mineral mixtures at 3% each, with a dietary energy of 380 kcal/100 g diet. Assume casein and gelatin to contain 93% protein with apparent protein digestibility of 96%, while dextrin is 100% digestible. Include feed additives such as attractant at 1% and binder at 2%.

Feed ingredients	Percentage
Gelatin	
Casein	
Dextrin	
Cod liver oil	12
Vitamin mix	3
Mineral mix	3
Feed binder	2
Attractant	1

Following the computation in Example 2 in the Trial and Error Method section, the amount of casein and gelatin would be 28 g each. The total dietary energy content of the above diet is:

50 g protein	x	4.5 kcal/g protein	=	225
12 g lipid	x	8.0 kcal/g lipid	=	96
		Total		321 kcal/100 g diet

The amount of dextrin will make up the remaining energy requirement. If the total dietary energy content is 380 kcal/100 g diet, then the amount of dextrin to be added should supply the energy difference which is 380 kcal − 321 kcal = 59 kcal. Since a gram of carbohydrate has an energy content of 3.3 kcal, therefore, 59 kcal divided by 3.3 kcal/g dextrin is 18 grams. To make the formula 100%, a filler, such as cellulose, can be used. The final composition would be:

Feed ingredients	%
Gelatin	28
Casein	28
Dextrin	18
Cod liver oil	12
Vitamin mix	3
Mineral mix	3
Feed binder	2
Attractant	1
Cellulose (filler)	5
Total	100

Summary

Feed is a very important component in the success of an aquaculture venture. With increased stocking densities, natural food in culture systems has to be supplemented with formulated feeds. It is important to know the nutrients required by the aquaculture species as these would be the starting point in feed formulation. A single feedstuff does not have all the required nutrients for growth, survival, and reproduction. Hence, it is necessary to know the nutrient content and levels in commonly used feedstuffs so that these can be combined to come up with the desired formulation by mathematical calculations.

Several mathematical methods can be used in feed formulation: the Pearson's square technique, the algebraic equation method, the trial and error method, and linear programming. The first two are simple, the third uses a worksheet, and the fourth requires a computer software. In balancing a ration, protein which is the major component of the diet is computed first, the energy (lipid and carbohydrate) levels of the diet are then adjusted to the desired dietary level.

Guide Questions

1. Name some methods in formulating diets. Give the advantages and disadvantages of each method.
2. Why is it important to know the nutrient content of feedstuffs and their levels before one can start formulating a feed?
3. Why is protein the first nutrient to be considered in formulating a diet?
4. Discuss factors to be considered and their importance in formulating a feed for a specific species.
5. Give at least 3 feedstuffs that are good sources of:
   a) protein
   b) lipids
   c) carbohydrate
6. Calculate the amount of fish meal and rice bran in a diet that contains 30% protein. The protein contents of fish meal and rice bran are, 60% and 15%, respectively.
7. Use the ingredients in Example 1 in the Trial and Error Method section in formulating a diet that will contain not less than 35% protein, dietary lipid of not more than 10% and dietary energy not less than 350 kcal/100g diet.

Suggested Readings

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