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Reduce, Recycle and Reuse of Crop Residues and Agro-Industrial Wastes for Sustainable Freshwater Finfish Production in Sub-Sahara Africa

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ABSTRACT

The cost of aquaculture feeds represents about 60-75% of the cost of intensive fish production. Aquafeeds for fishes such as tilapias and African catfishes are compounded from soybean and maize meals. Increasing pressure on the use of these crops by human population and livestock makes their use more expensive, thus stimulating the use of alternative feedstuff sources that are locally and widely available, such as agro-industrial wastes, which are commonly available in west Africa (SSA). Agro-industrial wastes are non-competitive feedstuffs that can be developed as components of aquafeeds. Aquafeeds constitute significant portions of the operating cost in aquaculture enterprises, of which protein is the most expensive. Fish meal (the conventional protein source) supports good fish growth, because of its protein quality and palatability. Good quality fish meal is scarce, and when/where available, it is very expensive. Hence, there is a compelling need to explore the use of alternative protein sources in combating the problem of escalating cost of aquafeeds. The aim therefore is to use agro-industrial by-products in aquafeeds as it is desirable due to their low prices, sustainability and availability.

Keywords: Fish production, aqua feed, crop residues, agro-industrial wastes, sub-Saharan Africa

INTRODUCTION

The aquaculture industry in West Africa is based on freshwater fishes cultivated under intensive (commercial) and semi-intensive (artisanal) production systems in ponds, reservoirs and cages. The cost of nutritionally complete aquafeeds represents about 60-75% of the cost of intensively reared fish (Lovell, 1989; De Silva & Anderson, 1995; Guillaume *et al*., 2001). Feeds for tropical omnivorous fish such as tilapias (*Oreochromis* spp., *Sarotherodon* spp., *Tilapia* spp.), common carp (*Cyprinus carpio*), *Heterotis niloticus* and African catfishes (*Clarias* spp., *Heterobranchus* spp. and their hybrids) are compounded from soybean and maize meals. Increasing pressure on the use of these crops by human population and livestock make their use more expensive. This, in turn, is stimulating the use of alternative feedstuff sources that are locally and widely available, such as agro-industrial wastes, which are commonly available in west Africa. Agro-industrial wastes are non-competitive feedstuffs that can perhaps be developed as components of aquafeeds. Aquafeeds constitute significant portions of the operating cost of aquaculture enterprises, of which protein is the most expensive. Fish meal (the conventional protein source) supports good fish growth, because of its protein quality and palatability (Lovell, 1989). Good quality fish meal is scarce, and when/where available, it is very expensive. Hence, there is a compelling need to explore the use of alternative protein sources, particularly underutilized and unconventional plant protein supplements, in combating the problem of escalating cost of aquafeeds (Reigh, 2008). The use of agro-industrial by-products in aquafeeds is desirable due to their low prices, sustainability and availability.

Most crops grown for cash and subsistence purposes have residues (leaves, seeds, peels, shoots, tubers, roots, pulps) that can be converted into useful products (Fagbenro and Arowosoge, 1991a, b). Usefully, when the residues generated are in large quantities, they are wasted. However, the crop residues could have greater nutritional value than the harvested part. Many of the residues traditionally used as animal (particularly ruminants) feed may have application as fish feeds under integrated aquaculture systems (Little and Muir, 1987. Such materials would be piled up in fish ponds to attract fish as decomposition occurs. The highly fibrous nature of such materials makes them poor and unpalatable direct fish feeds.

Tilapias (*Oreochromis* spp., *Sarotherodon* spp., *Tilapia* spp.) (Cichlidae), African catfishes (Clariidae) and the common/mirror carp (Cyprinidae) are the most widely cultured fish in west Africa and are suited to low-technology farming systems (Haylor and Muir, 1998). This is because of their popularity in the market, fast growth rate, efficient use of natural aquatic foods, propensity to consume a variety of supplementary feeds, omnivorous food habits, resistance to disease and resistance to handling, ease of reproduction in captivity and tolerance to wide ranges of environmental conditions.

The abundance of aquatic macrophytes in sub-Sahara Africa has created a dilemma and are often considered as a weed problem to be controlled, possibly using cultivated herbivorous fishes such as *Tilapia zillii* and grass carp (*Ctenopharyngodon idella*) (Cyprinidae) (Fagbenro and Akinbode, 1988). According to Edwards (1980), fishes show preference for different types of aquatic macrophytes based on succulence and taste and this will affect their usefulness in weed control. Notable aquatic macrophytes that are fed to fishes directly include the aquatic fern (*Azolla pinnata*), duckweeds (*Lemna* spp., *Spirodela* spp., *Wolffia* spp.), water lettuce (*Pistia stratiotes*), water spinach (*Ipomoea aquatic*), taro (*Colocasia esculenta*), water hyacinth (*Eicchornia crassipes*), alligator weed (*Alternanthera phylloxeroides*). Fish production using aquatic macrophytes is typified by high food conversion ratios (FCR) as a result of their high water content, and also reflects the poor digestibility of many green fodders (Edwards, 1980).

Feeds Used in Tropical Aquaculture

Tropical fish culture tends to focus on methods of increasing natural food of high protein and vitamin contents in ponds. However, under commercial culture conditions that involve high fish stocking densities, natural foods may become limiting. It is then that artificial or supplementary feeds become important. Consequently, the development of dry or semi-moist artificial feeds. Feeds are of three types, namely:

Type I

These are dry meals, colloidal suspensions or soft cakes which are consumed by fish by direct capture or by filtering the water. These are mainly uncombined agricultural products or by-products (agro wastes) and food industrial wastes. Examples include: (a) Primary products (whole grains), (b) By-products (brans, oilseed cakes, brewers' waste grains, flour mill wastes) and (c) Fresh leaves (processed/ ensiled leafy/green vegetables). Table 1 shows the nutrient content and feed conversion ratio of low-cost feeds typically used in fish culture in sub-Sahara Africa.

Type II

For convenience of storage, transportation and dispensing in automatic feeders and self-feeders, many fish feeds are prepared in dry pellet form. They can be hard (sinking), expanded (floating, encapsulated) with moisture content (<10%) or soft pelleted with moisture content of 18-20%. These are mainly combined and nutritionally balanced feeds.

Type III

Semi-moist feeds have moisture content of 37-40% and are prepared from frozen or fresh wet ingredients (fish silage, fish hydrolysate).

Nutritional Requirements of Cultivated Fishes

Protein

Protein is always considered first in aquafeed because it is the most expensive component (Tacon, 1993) and there are qualitative and quantitative requirements for dietary protein. The qualitative requirements deal with the level, availability, and relative proportions of specific amino acids. Apparent protein requirement of fish is tied to the general energy requirement at a given temperature, the fish's ability to gain weight, its size and age, as well as environmental stress such as stocking density, low dissolved oxygen supply or the presence of toxicants (Steffens, 1989). Fishes do not have a precise protein need, but they have requirements for all-balanced mixture of essential and non-essential amino acids in an appropriate source of high quality dietary protein. Protein requirement and the associated amino acid balance is the major determinant of growth in fish and is the major feed ingredient problem. Table 2 presents the protein requirements of tilapias, carp, *Heterotis* and catfishes.

Energy

Limited information is available on the energy requirement of fishes. Energy needs of fish are less than those of warm-blooded animals because fish do not have to maintain a constant body temperature. Fishes require less energy for muscle activity to maintain their position in water, compared with terrestrial animals, and require less energy to excrete nitrogen waste products than livestock (Steffens, 1989). Digestible energy of a feedstuff is the total (gross) energy minus the portion of food energy content voided in the faeces. Proteins ingested by fish are utilized as energy source. Energy-yielding or sparing nutrients (carbohydrates, lipids) can reduce the oxidation of protein to energy and hence improve the utilization of dietary protein (protein-sparing effect) (Sheperd and Bromage, 1988). The beneficial effects of the incorporation of such protein-sparing nutrients and the optimal ratios between protein and energy have been proposed for many cultivated fishes. Table 3 shows the protein: energy ratios in diets for tilapias, carp, *Heterotis* and African catfishes.

Essential Amino Acids (EAA)

Out of the 25 commonly occurring amino acids, ten are essential in aquaculture diets. These are arginine, histidine, isoleucine, leucine, lysine, methionine (spared by cystine), phenylalanine (spared by tyrosine), threonine, tryptophan and valine. The quantitative amino acid requirements for tilapias, carp, *Heterotis* and catfishes are presented in Table 4. The quantitative requirements for the African catfish in terms of some essential amino acids are yet unknown. The amino acid requirements for channel catfish may be taken as a guide for the requirements for the African catfish. All the non-essential amino acids are present in fish protein and are necessary for synthesis of body protein. They are classed as non-essential because they can be synthesized from other amino acids if they are not furnished in the diets.

Lipids and Essential Fatty Acids (EFA)

They are a ready source of energy for fish and they have the distinct advantage of being almost completely digestible. Fish metabolize fats efficiently as an energy source with concomitant sparing effect on the protein requirements to produce maximum growth. Fat levels in tilapia, carp, *Heterotis niloticus* and catfish diets are presented in Table 5. A balanced diet for both for energy and essential fatty acids should include lipids. Table 5 presents the quantitative requirement levels for essential fatty acids in tilapia, carp, *Heterotis niloticus* and catfish diets.

Table 1: Gross composition (%) of low-cost feeds and their feed conversion ratios.

	Moisture	Protein	Lipid	Fibre	NFE	Ash	FCR
Peanut cake	12.77	31.82	9.01	-	27.99	16.89	1.5
Soybean cake	15.86	37.03	9.43	4.81	28.03	4.84	1.3
Bean meal	13.62	43.75	7.56	4.15	26.91	4.01	4.0
Flour mill waste	14.85	15.0	0.64	-	69.05	0.46	4.7
Wheat	13.59	13.07	1.96	3.91	63.61	3.85	5.2
Wheat bran	10.5	13.9	4.2	10.5	55.6	5.3	4.6
Rice bran	11.2	15.8	16.05	6.63	47.4	14.8	5.9
Cocoa pod husk		6.51	1.10	30.25	48.71	13.43	5.23
Cocoa cake	12.9	24.9	5.0	9.0	42.1	6.1	5.12
Cottonseed cake							4.14
Macadamia presscake	8.1	33.4	12.6	2.6	43.3		3.14

Source: Cowx (1992), Fagbenro (1988a, b, c, 1993); NFE - nitrogen-free extracts, FCR - feed conversion ratio

Table 2: Quantitative dietary protein requirements for tilapias, carp and catfishes.

	Optimum (%)	Size (g)	Feeding regime (% body wt./day)
Oreochromis mossambicus	40	0.5-1.0	6
	50		
	30-35	6-30	3
Oreochromis niloticus	40	0.7-3	6
	35	0.013-0.26	15
	28-30	0.024	6
	25	9-17	Ad lib.
	35	0.56	4
	19-29	Juvenile	3
Oreochromis aureus	30	1-3	6
	36	0.3-0.5	8.8
	56	Fry-2.5	20
	34	2.5-7.5	10
O. niloticus x O. aureus	30	Grower	2-2.5
	24	3-8	3
Tilapia (Coptodon) zillii	35	1.3-3.5	5
	35-40	1.6	4
Clarias gariepinus	40-42		
Clarias isheriensis	37		
Clarias anguillaris	40		
Heterobranchus bidorsalis	40		
Heterobranchus longifilis	42.5		
Heterotis niloticus	31-34.5	3-62	Ad lib.
	36	18	Satiation
Cyprinus carpio	35	Grower	5
	34	Fingerling	Ad lib
	38	Fingerling	Ad lib

Sources: Jauncey (2000), Fagbenro and Akegbejo-Samsons (2000), Monentcham (2009).

Vitamins

Vitamins are required in trace amounts and are essential for normal growth, reproduction and health. There are two broad categories namely, water-soluble and the fat-soluble vitamins. The quantitative vitamin requirements for African catfishes are yet unknown; and the requirements for channel catfish may be taken as a guide for the requirements for African catfish. Minimum vitamin requirements of tilapias, carp and catfish are shown in Table 6.

Minerals

Fish require large amounts of Ca and P for growth and metabolism. Practical diets in which there is a slight predominance of Ca over P enhances good growth. The quantitative mineral requirements for African catfish have not been determined. The requirements for channel catfish may be taken as a guide for the requirements for the African catfish. The minerals required in diets of tilapias, carp and catfish are presented in Table 7.

Table 3: The protein:energy ratios in diets for tilapias, carp, *Heterotis* and African catfishes.

	Temperature	Size (g)	P/E (mg protein/kJ DE)
Oreochromis niloticus	21-25	12mg	26.3
		6	16-17
		14	17.9
Oreochromis aureus	31	2.5	29.9
	31	7.5	25.8
Oreochromis niloticus x O. aureus		0.16	26.5
		1.6	16.2-25
Oreochromis mossambicus		10-40	19.9
Tilapia (Coptodon) zillii		1	21
Sarotherodon melanotheron		7.5	17
Cyprinus carpio	23	4-10	21-23
	24	170-1200	21-23
	25	3	24
	23	11-15	21-26
	19-23	16-20	20-25
Clarias gariepinus	28	Fry	26-29
		Fingerlings	24
Clarias isheriensis		Fingerlings	22
Heterobranchus bidorsalis		Fingerlings	25
Heterobranchus longifilis		Fingerlings	26
Heterotis niloticus		18	25.1

Sources: Uys (1984, 1990), Steffens (1989), Wilson and Moreau (1996), Monentcham (2009)

Table 4: Essential amino acid requirements for tilapias, carp, *Heterotis* and catfishes.

EAA	*Oreochromis*				*Cyprinus*	*Heterotis*	*Clarias*		*Clarias*	Channel
(% protein)	*niloticus*	*mossambicus*			*carpio*	*niloticus*	*gariepinus*		*anguillaris*	catfish
Arginine	4.2	4.1	0.9	2.8	3.3	3.8	4.43	4.5	4.43	4.3
Histidine	1.7	1.5	0.9	1.1	2.1	1.4	2.15		2.22	1.5
Isoleucine	3.1	2.6	0.97	2.0	2.5	2.3	3.06		3.09	2.6
Leucine	3.4	4.3	1.14	3.4	3.3	4.1	5.22		4.94	3.5
Lysine	5.1		1.17	3.8	5.7	5.3	5.70	5.7	5.50	5.0
Methionine	2.7	1.3	0.6	1.0	2.1	1.6	1.83	3.2*	1.60	2.3
Phenylalanine	3.8	3.2	0.7	2.5	3.4	2.9	2.73	4.7**	2,77	5.0
Threonine	3.8	3.3	0.73	2.9	3.9	3.3	3.16		3.36	2.0
Tryptophan	1.0	0.6	0.53	0.4	0.8	0.6	0.71	1.1	0.69	0.5
Valine	2.8	3.0	0.77	2.2	3.6	2.9	2.90		2.85	3.0

Sources: Wilson and Moreau (1996), Fagbenro (2000), Fagbenro *et al*. (1998a, b, 1999, 2000), Fagbenro and Nwanna (1999), Jauncey (2000), Monentcham (2009). * Methionine + Cystine; ** Phenylalanine + Tyrosine

Table 5: Essential Fatty Acids (EFA) requirements for tilapias, carp, *Heterotis* and African catfishes.

	Lipid requirement	Essential fatty acids	
	(%)	Type	Level
Oreochromis niloticus	6-10	18:2n-6	0.5-1.0%
		20:4n-6	1%
Oreochromis aureus		18:2n-6 or 18:3n-3	1%
Tilapia (Coptodon) zillii		18:2n-6 or 20:4n-6	0.5-1.0%
Heterotis niloticus	13		
Cyprinus carpio		18:2n-6 and 18:3n-3	1% of each
Clarias gariepinus	8-12	n-3	0.5-1.0%
Heterobranchus longifilis		n-3	0.5-1.0%

Sources: Wilson and Moreau (1996), Jauncey (1993, 2000), Monentcham (2009).

Table 6: Vitamin requirements (mg or IU/kg diet) of tilapias, carp and Channel catfish.

	Cyprinus carpio	*Oreochromis spp.*	Channel catfish
	Water soluble		
B-complex vitamins			
Thiamine (Vitamin B_1)	2-3	2.5	1
Riboflavin (Vitamin B_2)	4-10	5-6	9
Pyridoxine (Vitamin B_6)	4-10	3	3
Pantothenic acid	25-50	6-10	10-15
Nicotinic acid (niacin)	28-50	ND	14
Biotin	1-2.5	ND	1
Folic acid	35	ND	1.2
Vitamin B_{12} (cyanocobalamin)	NR	NR	NR
Macrovitamins			
Inositol (myo-inositol)	200-440	ND	NR
Choline	500-4000	NR	400
Vitamin C (Ascorbic acid)	100-150	1250	11-60
	Fat soluble		
Vitamin A (retinol) (IU)	1000-2000	ND	1000-2000
Vitamin D (D3-cholecalciferol) (IU)	ND	375	250-1000
Vitamin E (tocopherol)	80-300	10-100	20-50
Vitamin K (K_3 menadione)	ND	ND	ND

Sources: Tacon (1993), Wilson and Moreau (1996), Jauncey (2000), Guillaume *et al*. (2001).
NR = not required; ND = no available data

Table 7: Mineral requirements (mg/kg or g/kg dry diet) of tilapias, carp and Channel catfish.

	Cyprinus carpio	*Oreochromis spp.*	Channel catfish
Major elements			
Calcium	300mg-3g	7g	4.5g
Phosphorus	6-6.5g	4.5-10g	4.2-4.5
Magnesium	400-700mg	0.5-0.8g	400-700mg
Potassium			26mg
Trace elements			
Iron	200mg		30mg
Copper	3mg		5mg
Manganese	12-13mg	12mg	2.4mg
Chromium		2-139.6mg	
Zinc	15-30mg	20-30mg	20mg
Selenium			0.25mg

Sources: Steffens (1989), Wilson and Moreau (1996), Jauncey (2000), Guillaume *et al*. (2001).

Evaluation of Feedstuffs Used in Aquafeeds

According to Jauncey (1998), there are many difficulties associated with the utilization of feedstuffs by freshwater fishes. Rarely are the feedstuffs in experimental investigations adequately defined [type (strain, variety, etc.), processing, nutrient levels (including digestible crude protein and digestible energy), levels of toxins and antinutrients]. Frequently, esoteric protein sources are studied with little thought about their possible future economic viability. Before embarking on evaluating any feedstuff, much information on the feedstuff can be gained from the literature and *in vivo* analyses such as:

a. Protein content
b. Lipid content
c. Carbohydrate content
d. Mineral content
e. Vitamin content
f. Energy content
g. Microbial content
h. Presence of toxic and/or anti-nutritional factors
i. Variability in composition
j. Storage characteristics
k. Pelleting/handling characteristics
l. Cost and availability
m. Palatability to target species
n. Effect of consumer acceptance of the final product, including its state as well as taste.

Having performed literature and in vivo studies, it will then be appropriate to start biological evaluation with a brief palatability/digestibility study and only if this proves promising will it be worthwhile to proceed to a full scale feeding/growth study. If only this simple approach were more widely adopted, much time and funds could be saved, particularly in duplication of research effort.

Table 8: Feedstuff digestibility in tilapias, carp, *Heterotis* and African catfishes.

	Tilapias		Carp		*Heterotis*		African catfishes	
	APD	AED	APD	AED	APD	AED	APD	AED
African locust bean	82.1	75.9						
Brewers' grain	62-63							
Cassava meal							-	74
Cocoa pod meal							79	50
Copra meal	99.1							
Corn gluten meal					82.6	60.1		
Corn grain	79-89.4		78.2	52.6			92-97	25-58
Corn starch							-	86
Cottonseed meal	31		87		86.8	60.9	76-83	59-80
Groundnut/peanut meal	79				83.6	66.5	74-86.6	66-76
Jack bean	84.7	65.2						
Lima bean	85.2	56.3						
Millet grain			70.9	46.3				
Macadamia presscake							83.5	78.6
Pigeon pea	81.9	66.5						
Rice bran	93		76.6	49.5			73-78	50-53
Sesame meal					82.0	62.7	80.1	64.8
Sorghum grain			71.4	48.0			58	49
Soybean meal	88.5-94	76.4			93.5	77.4	72-90	85
Sunflower meal					90.5	63.8	86.5	79.2
Velvet bean	80.5	58.2						
Wheat bran	20							
Wheat grain	90							
Wheat middlings	75		79.1-85	50.0			88-92	60
Winged bean meal	86.4	78.6						

Source: Tacon (1987), Steffens (1989), Fagbenro (1996, 1998a, b, 1999, 2001)
APD = Apparent protein digestibility, AED = Apparent energy digestibility

Crop Residues and Agro-Industrial Wastes Used in Aquafeeds

Oilseed meals/cakes

Most oilseeds are tropical in origin and tend to be rich in protein. Their EAA profiles are often unbalanced, with lysine, methionine and threonine generally being deficient and tryptophan and arginine present in excess (Tacon, 1987). Oilseeds are low in carbohydrates and are generally poor sources of calcium, vitamin E and pro-vitamin A, but good sources of phosphorus and vitamin B. Their lipid content may vary from the non-extracted 'full fat' form to the lower lipid, extracted meals. Mechanically-extracted oilseeds tend to have a 5-10% higher final lipid content and better palatability than solvent-extracted products (Tacon, 1993). Oilseeds are primarily grown to supply oils for direct human consumption. The resultant feedstuffs are available in by-product form, mostly as lipid-extracted meal. Oilseed feedstuffs represent some of the most promising plant materials for inclusion in aquafeeds.

Cereals

Cereals, especially their by-products, are generally very cheap. However, their supplies can be limited as much of the cereal grown in the tropics is for human consumption. Most cereals have high carbohydrate contents, consisting principally of starch, which gelatinizes during pelleting (due to the heat) to improve final pellet stability (Tacon, 1987). Protein levels in cereals are low, with lysine and threonine usually being the first limiting EAA. Cereal oils are normally unsaturated and are prone to rapid oxidation and rancidity during storage. Although cereals contain little calcium, vitamins C, D or pro-vitamin A, they are good sources of phosphorus, vitamin E and most vitamin B complexes. Some cereals contain endogenous anti-nutritional factors (Tacon and Jackson, 1985).

Legumes

Legumes (pulses) are plants widely cultured for their foliage (used as terrestrial animal fodder) and seeds (peas, beans) which are used extensively for human consumption. Legumes generally have a high feedstuff value, being rich in protein, energy (carbohydrate or lipid), minerals and several B complex vitamins (thiamine, riboflavin, nicotinic acid). However, they often contain endogenous anti-nutritional factors or toxins which require destroying with heat treatment before they can be safely fed (Tacon, 1993). Legume meals are prone to lipid rancidity after only few weeks storage.

Roots/tubers

Root crops are those plants primarily grown for their underground stems (tubers) or roots and are generally excellent sources of carbohydrates (sugar in root crops, starch in tubers). They are low in protein, calcium, phosphorus and vitamins; rich in potassium, and often contain anti-nutritional factors which require destroying before they can be used (Tacon, 1987).

With known information on nutritional requirements of fish species, the approximate composition of a range of feedstuffs and a knowledge of constraints and anti-nutritional factors, a diet can be formulated. This involves fixing of a large number of variables between maximum and minimum levels as well as in relative proportion and interactions with one another. Feedstuff formulation also involves balancing the amino acid profile, the levels of crude protein, crude lipid, crude fibre, non-fibrous energy, ash and maybe total energy. Where possible, regard should be taken of palatability, digestibility, cost, pelletability and toxins of the feedstuff. According to Jauncey (1993), the most important characteristics of feedstuffs in terms of feed formulation are the possible toxic/anti-nutritional components and associated palatability problems as well as their digestibility, particularly in terms of digestible crude protein (DCP) and digestible energy (DE). The digestibility of crude protein and gross energy in some practical feedstuffs digestibility by tilapias, carp, *Heterotis* and African catfishes are presented in Table 8.

CONCLUSION

Increasing the production and availability of food fish in sub-Sahara Africa is of significant importance if the human populations in the region are to be adequately fed. There are many measures that such countries can implement in order to alleviate this challenge which include:

- Maximizing the efficiency of current aquaculture production systems so that all existing resources, (human skills, animals, facilities, feeds) are used as efficiently as possible.
- Establishing the agro-industrial by-products in a country that are currently either unused or used inefficiently.
- Developing local crops that can be grown to supply the nutrients currently obtained from imported feeds or feeds that might be better used by humans.

The particular materials to be considered clearly fall into the last two measures, though all points should be considered in resolving the overall problem. In particular, the first measure is relevant to the application of the other two. Even in developed countries with well-established traditions of by-product utilization, the value of agricultural by-products (crop residues) or non-traditional feedstuffs has, until very recently, been undervalued. In many such countries, this view has now been replaced with an appreciation of their true worth. The profitability of many aquaculture industries now depend on the use of feeds largely consisting of agricultural by-products. This change in the traditional approach to aquaculture feeding has led to a more responsible approach to nutrient supply, involving the use of crops on the basis of the yields of total nutrients per unit of land and the cost of production of each nutrient. On this basis alone, this should result in the utilization of less cereal and more root and tuber crops in many traditionally cereal producing areas.

On the basis of their composition, crop residues would appear to have considerable potentials to substitute for nutrients provided at the present by fishmeal and cereals in aquafeeds. Although the residues would appear to be able to completely replace the energy component in aquaculture feeds, they would be unable to provide other dietary nutrients as well as cereal grains. The lower protein content of the residues could also be compensated for by better utilization of locally produced protein sources such as agro-industrial by-products. High quality feeds improve the quality of the edible portion of fish, enhance high protein retention and give flesh a firm consistency and delicate flavour.

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