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Tropical agricultural residues and their potential uses in fish feeds: the Costa Rican situation

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Abstract

In Costa Rica as many other tropical countries, the disposal problem of agricultural wastes is widely recognized but efforts to find solutions are not equal for different sectors. This study describes the situation of major agricultural residues in Costa Rica, identifying the activities with higher amounts produced and, the potential use of these residues in fish feeds. In Costa Rica, during the 1993–1994 production season, major agricultural sectors (crop and livestock) generated a total amount of 3.15–3.25 million MT of residues (classified in by-products: used residues and wastes: not used residues). Some residues are treated to turn them into valuable items or to diminish their polluting effects (e.g., the so-called by-products). About 1.56–1.63 million MT of by-products were used for different purposes (e.g. fertilization, animal feeding, fuel, substrates in greenhouses). However, the remainder (1.59–1.62 million MT) was discharged into environment causing pollution. About 1.07–1.2 million MT wastes came from major crop systems (banana, coffee, sugarcane and oil palm) whereas the remainder came from animal production systems (porcine and poultry production, slaughtering). These data are further compared to residues estimates for the 2001–2002 production season coming from the biggest crops activities. Unfortunately, most of the studied wastes contain high levels of moisture and low levels of protein, and also contain variable amounts of antinutritional factors (e.g., polyphenols, tannins, caffeine), high fibre levels and some toxic substances and pesticides. All these reasons may limit the use of these agricultural wastes for animal feeding, especially in fish feeds. The potential use of the major vegetable and animal residues in fish feeds is discussed based on their nutritional composition, on their amount available over the year and on their pollution risks. Other constraints to use these wastes in fish feeds are the extra costs of drying and, in most cases, of transportation from several dispersed locations. It was stated that most interesting wastes are rejected green banana and coffee pulp.

1. Introduction

Agriculture generates residues, which can be used (by-products) or disposed of (wastes). Crop and animal wastes are a recognized source of environmental pollution and, therefore, efforts are made to use or recycle them. In Costa Rica as in other tropical countries, these efforts vary in the different regions and do often not keep pace with production.

One of the most logical outlets for (re-)using agricultural wastes and/or by-products is in animal feed production. The use of so-called low value crop wastes might be of particular interest, especially in areas where low market prices for animal products force farmers to use inexpensive feeds.

According to their nutritional composition, volume and pollution risk, some wastes like rejected green banana, coffee pulp and mucilage, sugarcane, cocoa and fruit processing wastes may have a potential for use in animal feeds, including fish feeds. In many tropical regions of Asia and Africa, wastes from crops, agro-industry and animal production are commonly used in aquaculture. They are used as feed ingredients, as supplementary feeds or as pond fertilizers (Ravishankar

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and Keshavanath, 1986; Wohlfarth and Hulata, 1987; Subosa, 1992; Tacon, 1993,1994).

However, the use of agricultural wastes as an ingredient in fish feeds may be restricted by nutritional aspects (e.g., high fibre and low protein levels) and presence of antinutritional factors (ANFs) (e.g., polyphenols, tannins, caffeine), which may limit their inclusion at high levels in the feeds. Fortunately, the ANFs can be destroyed or inactivated totally or partially, thereby increasing the nutritional value of the wastes. Other negative aspects of using agricultural wastes in animal feeds are the presence of toxic substances and pesticides, which, in the case of aquaculture, may accumulate in pond sediments and fish (Pullin, 1993).

To evaluate the potential of the most important animal and crop residues from Costa Rica as foodstuffs for fish diets, first, an inventory was made to collect information on their volume, their availability over time and their present use. In addition, we determined the proximate composition, presence of ANFs and pollution risks of most important wastes. To achieve the objective of this study, the inventory was mainly focused on agricultural solid residues. Consequently, the potential use of major wastes in fish feeds was evaluated based on the above mentioned criteria.

2. Material and methods

2.1. The inventory

The major residues in Costa Rica were identified in an inventory done during 1995 and reported on at a conference by Ulloa (1997). The data are being presented in this publication and they referred to the 1993–1994 production season. Residues were classified as by-products (used residues) and as wastes (not used residues). The inventory included type and amount of residues, quantities used or disposed of (on/of-farm) and seasonality. The residues were categorized in two groups according to their origin: (a) animal production and, (b) crop production. Residues from animal origin included those coming from slaughterhouses (processing wastes) and those from production units (manures). Crop residues included those generated in the plantations (some banana, sugarcane, coffee, oil palm, cocoa wastes) and those generated in the processing plants (e.g., coffee, sugarcane, cocoa, rice, fruit wastes).

Data were obtained from production corporation reports, interviews to producers and governmental institutions.

The same procedure was used to obtain information on the agricultural situation of major crop activities (sugarcane, banana, coffee, oil palm, rice and cocoa, identified from 1993 to 1994 inventory) during the 2001–2002 production season. Data on the amount of residues generated by the major crop activities during both production seasons (1993–1994 and 2001–2002) were compared and some conclusion were drawn.

2.2. Residues sample collection and analysis

All residues were collected directly from their respective plantations or processing plants. Three different samples of about one kilogram each were collected from the residues batches at the processing plants. Residue samples were stored in labeled and sealed plastic bags, transported to the laboratory and kept frozen (−15 °C) when they were not processed immediately.

In most cases, fresh residues (wet or "dry") were dried at 100 °C for 12 h to determine their moisture content. Then dried residues were ground at 1-mm particle size and stored in desiccators for further analysis. The proximate composition (crude protein, crude fat, crude fibre, crude ash and moisture) of various residues was determined by standard methods (AOAC, 1990). The NFE (nitrogen free extract) was calculated by difference between the sum of the above parameters and total wet weight. The "total utilizable carbohydrate" (starch and sugars) was measured by the Anthrone method and expressed as glucose (g kg^{-1}) (Osborne and Voogt, 1986). All chemical determinations were done in triplicate and expressed as g kg^{-1} of dry matter (DM). In some cases, the proximate composition of residues was obtained from their producers and this was indicated in the corresponding tables. In this case, the standard methods used were corroborated from the chemical laboratories that performed those analyses.

To select the most relevant residues from the inventory (Table 1), the following criteria were considered: (a) their total amounts produced and amounts disposed of, (b) their use in animal feeding, (c) their nutritional composition and (d) their environmental risks. The wastes with proven potential for use in animal feeds were more fully evaluated.

3. Results

3.1. The major agricultural residues in Costa Rica

From an economic point of view, banana, coffee, and milk and beef industries represent a large proportion of the total Costa Rican export income. In the 1993–1994 season, solid residues from the most important agricultural (crop and livestock) sectors reached 3.15–3.25 million MT fresh weight (Table 1). About 1.59–1.62 million MT of solid wastes were disposed into the environment. From this amount, crops contributed 1.38–1.41 million MT.

Table 1
Residues (wastes and by-products) from the most relevant agricultural activities in Costa Rica during the season 1993–1994

Residues[a]	Amount (×1000 MT)	Used-on farm (%)	Used-of farm (%)	Disposed on-farm (%)	Disposed of-farm (%)
Animal origin					
Processing wastes					
Cattle	≈54	35–36	≈1.5	25–30	34–37
Swine	≈47	≈90	Few	≈9	≈0.5
Poultry	26–30	60–69	29–38	0	1.5–2.0
Fisheries	≈12	≈60	≈5	0	34–37
Aquaculture	≈2	0	≈96	Few	4–5
Manures					
Swine	≈117	≈0.5	0	Few	98–99
Poultry	36–40	≈36	≈64	0	0
Subtotal	294–302				
Plant origin					
Sugarcane	1444–1520	70–72	11–12	≈21	0
Banana[b]	≈563	0	41–55	43–59	Few
Coffee	532–547	16–18	0	55–57	26–27
Oil palm	≈148	≈23	≈17	≈61	0
Rice	≈87	0	41–44	0	56–59
Fruits	≈45	0	≈0.5	≈88	10–12
Cocoa	≈37	Few	≈2.0	≈94	3–4.5
Subtotal	2856–2947				
Total	3150–3249				

[a] Sugarcane: harvesting residues (variable amounts of leaves, stalk pieces, flowers sticks), bagasse, molasses, mudpress and boiler ash. Banana: rejected green banana, peels, banana seeds and fruit bunches. Coffee: pulp, seed husks and mucilage. Oil Palm: kernel meal, kernel spill, hulls, mesocarp and fruit bunches. Rice: hulls, bran and broken rice. Fresh Fruit Processing: pulp, seeds and peels from orange, pineapple, mango, papaya. Cocoa: seed shells, pods and fermented liquid. Cattle, swine and poultry slaughterhouse residues: e.g., blood, bones, hoofs, digestive tract and its content, rumen content, fat, feathers. Fisheries and Aquaculture: fish and shrimp processing residues. Pig manure: solid fraction of the manure of pigs receiving a diet based on a mixture of maize/soybean. 5.8–9.6% of 5.2–6.5 million liter cattle blood and 9–10% of 0.55 million liter pig blood were not used.

[b] This estimate does not include harvesting residues: 456,000 MT (stems, leaves, banana bunches) that are left on the plantations.

The major amounts of solid residues not used (wastes) were generated by the coffee, banana, sugarcane and oil palm industries, with annual production of 408–423,000 MT, 375–421,000 MT, 328–404,000 MT, and 89,700 MT, respectively. Livestock generated about 159–162 thousands MT of wet-solid wastes (Table 1). In the 2001-2002 season, some of the major crop activities (sugarcane, oil palm and rice) presented an increase in the amount of solid residues generated compared with the figures of 1993–1994 season, whereas others crops showed a reduction (banana, coffee and cocoa). The estimates of total produced residues are: ≈1,730,000 MT for sugarcane, ≈521,000 MT for banana, ≈488,000 MT for coffee, ≈221,000 MT for oil palm, ≈141,000 MT for rice and only ≈7000 MT for cocoa (Table 2). The corresponding amount of wastes produced by the latter mentioned crops also showed a similar trend than total residues, except for banana: ≈329,000 MT for sugarcane, ≈354,000 MT for banana, ≈366,000 MT for coffee, ≈126,000 MT for oil palm, ≈83,000 MT for rice and only ≈4300 MT for cocoa (Table 2 and Table 3). The most important remark when comparing both figures, from 1993–1994 and 2001–2002, is the change in the amount of residues produced as a direct consequence of the variation (reduction or increment) of the crop production. Coffee, banana and specially cocoa showed a reduction in the 2001–2002 production season, which have been declined progressively since 1993–1994 season, whereas sugarcane showed a steady production in last three years and, rice and oil palm increased their production.

3.2. Residue utilization

From the inventory of the 1993–1994 production season, it was determined that some residues (by-products) were used partial or totally as animal foodstuffs and feeds, fertilizers and/or soil conditioners (Table 4). The use of solid residues as animal foodstuffs and/or whole feeds represented about 10.7–11% of total residues (≈400,000 MT). Some residues such as palm kernel meal, sugarcane molasses, rice bran, broken rice and poultry processing residues where completely used as foodstuffs; others were partly used (rejected green banana, banana peels, cattle and piggery slaughtering and fish and shrimp residues). The use of residues for fertilizers and/or soil conditioners only reached 5–5.1% (≈122,000 MT, e.g., some coffee pulp and mucilage, sugarcane boiler ash and poultry manure). Some other residues were also used partly or completely as energy sources in the same processing plants, as substrates in green houses and in poultry enclosures, as fillers in food technology and/or for human consumption (1,215,000 MT, 32.4–33.6% of total residues). They included coffee hulls, green banana, oilpalm hulls and mesocarp, sugarcane bagasse and rice hulls (Table 4). Data from 2001 to 2002 residues production season revealed a small increment in the use of coffee pulp and cocoa residues for fertilizers and/or soil conditioners (about 20% for coffee and 50% for cocoa) and the use of rejected green banana for local human consumption. The other wastes maintained a similar proportion of residue usage compared with 1993–1994 season.

From the above analyzed information, it can be suggested that the most highly available wastes, in terms of amount, utilization and pollution risks, are rejected green banana and coffee pulp.

Table 2
Residues (wastes and by-products) from the biggest agricultural activities in Costa Rica during the season 2001–2002. (Residues were selected from Table 1)

Residues[a]	Amount (×1000 MT)	Used-on farm (%)	Used-of farm (%)	Disposed-on farm (%)	Disposed-of farm (%)
Crops					
Sugarcane	≈1730	≈70	≈11	≈19	0
Banana[b]	≈521	0	≈32	≈65	≈3
Coffee	≈488	≈25	0	≈50	≈25
Oil palm	≈221	≈21	≈22	≈57	0
Rice	≈141	≈3	≈38	0	≈59
Cocoa	≈7	≈39	0	≈57	≈4
Total	≈3108				

[a] As described in Table 1.
[b] This estimate does not include harvesting residues: ≈408,000 MT (stems, leaves, banana bunches) that are left on the plantations.

Table 3
Biggest individual agricultural residues produced (MT×1000) in Costa Rica during 2001–2002 production season and their proportional use (%). (Residues were selected from Table 1)

Residues[a]	Total amount	Animal feeding	Fertilization	Other uses[b]
Crops				
Sugarcane				
bagasse	≈1108	≈5	0	≈95
melaza	≈173	≈52	0	≈48
mudpress	≈114	0	< 5	0
Banana				
rejected green banana	≈290	≈20	0	≈37
fruit bunches	≈214	0	0	0
ripe peels and seeds	≈55	≈30	0	0
Coffee				
pulp	≈323	0	≈20	≈2
mucilage	≈126	0	≈20	≈2
hulls	≈39	0	0	100
Oil palm				
fruit branches	≈125	0	0	0
mesocarp fiber	≈40	0	≈2	≈98
hulls	≈28	≈75	0	≈25
kernel seed	≈28	100	0	0
Rice				
hulls	≈87	0	0	≈10
bran	≈38	100	0	0
broken	≈15	≈90	0	≈10
Cocoa				
pods and seed shells	≈7	0	≈38	0
Total	≈2810			

[a] Residues as defined in Table 1.
[b] Other uses: e.g., energy source, human feeding, poultry bedding, others.

Table 4
Major individual agricultural residues produced (MT×1000) in Costa Rica during 1993–1994 production season and their proportional use (%). Residues without any use were no included

Residues[a]	Total amount	Animal feeding	Fertilization	Other uses[b]
Animal origin				
Cattle slaughtering	≈54	≈35	0	0–1
Poultry processing	≈18	100	0	0
Swine processing	≈5	11	0	0
Fish and shrimp	≈14	64–69	0	0
Cattle and pig blood	5.7–7 million l	5.3–6.4 million l	0	0
Manures				
Swine	≈117	0–1	0	0
Poultry	36–40	< 5	≈95	0
Subtotal:	244–248			
Vegetable origin				
Sugarcane				
bagasse	≈995	0–5	0	98–100
molasses	≈120	≈53	0	≈47
mudpress	≈99	0	Unknown	0
Banana				
Rejected green banana	≈324	2–5	0	39–50
Ripe peels and seeds	≈32	≈30	0	0
Coffee				
pulp	350–365	0	15–17	0–1
mucilage	≈142	0	15–17	0
hulls	≈40	0	0	≈100
Rice				
hulls	≈54	0	0	5–10
bran and broken rice	≈32	≈90	0	≈10
Fruits				
Orange and pineapple	≈39	0	0–1	≈1
Cocoa				
Cocoa pods / seed shell	≈35	1.5	0–1	0
Oil palm				
kernel and hulls	≈30	≈50	0	≈50
mesocarp	≈28	0	1–2	98–99
Subtotal:	2320–2335			
Total:	2564–2583			

[a] Residues as defined in Table 1.
[b] Other uses: e.g., energy source, human feeding, poultry bedding.

3.3. Residue treatments and disposal methods

It was estimated that about 50% (1.6–1.62 million MT) of produced solid residues are usually disposed of in different ways. Part of the pig manure (from rural areas), cocoa (husks), oil palm (bunches and mesocarp), coffee pulp, sugarcane and banana wastes are spread on open fields. Some wastes are also often buried near where they are generated or in municipality dumps (e.g., cattle slaughtering residues from rural areas, some fish and shrimp residues, fruit processing, some coffee pulp). Some other wastes are partly used as a soil conditioners and/or fertilizers and they are just disposed of on-farm (e.g., coffee pulp, sugarcane mudpress and boiler ash, oil palm mesocarp). The amounts of the wastes disposed of by the latter methods are difficult to estimate and, in many cases, are unknown. From 2001 to 2002 inventory, it was stated that an important fraction of coffee pulp is actually buried near coffee processing units.

In some cases, solid wastes are treated by biological means, oxidation lagoons or septic tanks (e.g., some pig manure, fruit wastes); physical means (separation of solid fraction by sieving, e.g., poultry manure, coffee pulp and sugarcane mudpress) before disposal or utilization. The amounts of solid wastes treated in this way are also unknown and difficult to estimate.

The way of disposal of rejected green banana, coffee pulp, sugarcane mudpress, in some cases, still poses a pollution risk on the environment, by producing bad smells and/or by being a substrate for flies and mosquitoes reproduction. Therefore, more efforts have to be done to intensify and improve the use of the present treatments but also to find other alternatives to manage the residues not used. Mostly, economical reasons are limiting the application and improvement of the present wastes treatment and disposal methods.

3.4. Nutrient composition of agricultural wastes

Proximate composition, energy content and presence/absence of ANFs are given in Tables 5 and 6. Most of the animal and crop wastes have a high level of moisture (above 700 g kg^{-1}) as they are obtained "*in situ*".

3.4.1. Wastes from crop origin

Most of the crop residues contained several ANFs (e.g., phenols, tannins, caffeine, and threobromine) and high fibre levels. The rejected green banana and fruit processing wastes (e.g., orange, pineapple) are mainly characterized by a high level of "carbohydrate" (as NFE), a low level of protein (except for papaya) and by an intermediate fibre content (except for some banana residues). Coffee, sugarcane, cocoa and oilpalm and rice hulls wastes contained high fibre levels and low protein and energy contents (Tables 5 and 7).

Papaya residues had the highest gross energy content; followed by the green banana meal, and some fruit residues (17.8–21.7 kJ kg^{-1}). Theoretically, the digestible energy for fish is also higher in these residues and accounts for more than 52% of the gross energy whereas for the other wastes this is less than 50%. According to the nutritional composition, the rejected green banana may have a high potential for animal feed manufacturing.

3.4.2. Wastes from animal origin

The wastes from fish and shrimp are characterized by a high ash and protein contents. The highest gross energy content was found in the tilapia wastes (24.2 kJ g^{-1}) and in the blood (23.2 kJ g^{-1}). At present, almost all tilapia wastes are used in animal feed manufacturing and the other wastes are partly used because of their small amount produced and the dispersed location of many small processing units.

Poultry and pig manures presented the highest crude fibre contents and the lowest gross energy contents, 12.9 and 17.8 kJ g^{-1}, respectively. The potential digestible energy for fish also presented the same trend as gross energy (Tables 6 and 8).

4. Discussion

The feasibility for some agricultural wastes, based on nutritional aspects, to be included in diets for omnivorous fish has been indicated in several studies, especially, when they are reared in extensive or semi-intensive systems (earthen ponds or cages located in ponds) (Sehgal and Sharma, 1993; Bautista et al., 1999; Rathbone et al., 2001).

4.1. Residues from animal origin

Despite some of the animal residues (e.g., fish and shrimp wastes, blood, cattle processing wastes) found in Costa Rica showed to be nutritionally acceptable for fish feeds (high protein and energy content, Tables 6 and 8), part of them are still disposed of. They may be good alternatives to fish meal in fish feeds if included at dietary levels of 200–500 g kg^{-1} in well balanced diets (Dean et al., 1992; Moon and Gatlin, 1994; Webster, et al. 1999; Rathbone et al., 2001; Li et al., 2002). At present, most of tilapia processing wastes are used as a meal in animal feed manufacturing. The main constraints to use some of these wastes in Costa Rica and, maybe in other tropical countries, are the relatively small amounts produced (e.g., shrimp processing, cattle and pig wastes) and their transportation costs from many dispersed processing plants.

Table 5
Proximate composition (g kg^{-1}, DM), energy content (kJ g^{-1}, DM) and the presence of ANFs in several crop residues. Analysis done in our laboratory

Residues[a]	Component								
	Gross energy[b]	Energy for fish[c]	Crude ash	Crude fibre	Crude fat	NFE	Crude protein	ANFs	Moisture (g kg^{-1})
Green banana	17.8	11.4	49	16	58	818	59	Yes	810
Coffee pulp	16.9	4.8	89	571	29	189[d]	122	Yes	850
Rice hulls	≈14.7	3.6	179	537	10–20	194[d]	75	Yes	109
Fresh pineapple	17.5	9.6	37	150	39	724	50	Yes	840
Fresh papaya	21.7	13.4	86	182	205	295[d]	232	Yes	>800
Other fruits	14.5–17.9	7.5–9.7	28–42	188–389	52–54	438–687	45–77	Yes	810-840

[a] Residues as defined in Table 1.
[b] Gross energy (kJ g^{-1}): protein (g kg^{-1})×23.87 + fat (g kg^{-1})×39.78 + NFE (g kg^{-1})×16.87 (DM basis).
[c] Potential digestible energy for fish, calculated according to digestible energy coefficients for *Ictalurus punctatus*, 14.6 kJ g^{-1} protein, 33.9 kJ g^{-1} fat and 10.5 kJ g^{-1} crude carbohydrate (N.R.C., 1977).
[d] Measured as "total utilisable carbohydrate" by the Anthrone method of Clegg and expressed as glucose (Osborne and Voogt, 1986).

Table 6
Proximate composition (g kg^{-1}, DM) and energy content (kJ g^{-1}, DM) of several residues from animal origin. Analysis done in our laboratory

Residues[a]	Component							
	Gross energy[b]	Energy for fish[c]	Crude ash	Crude fibre	Crude fat	NFE	Crude protein	Moisture (g kg^{-1})
Shrimp residues	18.2	7.9	330	157	29	29	456	730
Tilapia residues	≈24.2	13.5	259	≈10	150	20–30	560	700
Slaughterhouse sludge	13.5–19	9–11.9	130–230	160–270	110–190	170–410[d]	70–250	810–920
Pig manure	17.8	7.4	59	399	52	375[d]	115	759

[a] As in Table 1.
[b] Gross energy (kJ g^{-1}): protein (g kg^{-1})×23.87 + fat (g kg^{-1})×39.78 + NFE (g kg^{-1})×16.87 (DM basis).
[c] Potential digestible energy for fish, calculated according to digestible energy coefficients for *Ictalurus punctatus*, 14.6 kJ g^{-1} protein, 33.9 kJ g^{-1} fat and 10.5 kJ g^{-1} crude carbohydrate (N.R.C., 1977).
[d] Measured as "total utilisable carbohydrate" by the Anthrone method of Clegg and expressed as glucose (Osborne and Voogt, 1986).

Table 7
Proximate composition (g kg^{-1}, DM), energy content (kJ g^{-1}, DM) and the presence of ANFs in several crop residues. Data on proximate composition according to residue producers

Residues[a]	Component								
	Gross energy[b]	Energy for fish[c]	Crude ash	Crude fibre	Crude fat	NFE	Crude protein	ANFs	Moisture (g kg^{-1})
Sugarcane:									
Bagasse	16.6	7.6	30–40	430	≈10	≈500	20–30	Yes	450–500
Harvesting residues	16.5	6.7	59	345	10	532	54	Yes	700
Oilpalm hulls	≈17.7	6.2	24	497	40–50	390–410	33	Yes	124
Cocoa pods	16.1	7.5	86	243	8	598	66	Yes	850
Cocoa seed hulls	17.8	8.5	121	245	53	422	159	Yes	117

[a] As in Table 1.
[b] Gross energy (kJ g^{-1}): protein (g kg^{-1})×23.87 + fat (g kg^{-1})×39.78 + NFE (g kg^{-1})×16.87 (DM basis).
[c] Potential digestible energy for fish, calculated according to digestible energy coefficients for *Ictalurus punctatus*, 14.6 kJ g^{-1} protein, 33.9 kJ g^{-1} fat and 10.5 kJ g^{-1} crude carbohydrate (N.R.C., 1977).

Pig and poultry manures have a low nutritional quality (Tables 6 and 8) and therefore, their potential to be used as fish feed ingredients is relatively low as confirmed by several studies (Watson, 1985; Sehgal and Sharma, 1991). In addition, they may contain ANFs and they are produced in very dispersed areas. The use manures in aquaculture is mainly restricted as pond organic fertilizers in extensive or semi-intensive cultures (Wohlfarth and Hulata, 1987; Subosa, 1992), discussion that is beyond the scope of this paper.

4.2. Residues of plant origin

Several constraints were recognized to use crop wastes in fish feeding. From the nutritional view point, we found that many crop residues contain ANFs, high levels of lignin and cellular wall components (e.g., cellulose, hemi-cellulose, pectines) and consequently, low energy contents. In animals, the main negative effects of the ANFs are the reduction of growth and feed utilization (Krogdahl, 1989; Mueller-Harvey and McAllan, 1992; Tacon, 1994).

Fortunately, most of these crop wastes can be nutritionally upgraded by biological (fermentation, ensilage, fungi), chemical (alkali and acids) or physical treatments (heating, drying, soaking in water, cooking), or their combinations, before being used in animal feeds (López and Pabón, 1986; El Boushy and van der Poel, 1994; Ulloa et al., 2003).

In the next paragraphs, some of the major crop wastes (coffee pulp and rejected banana) found in the country are studied into more detail because of their volume available, their high pollution risk, their nutritional composition and their facility to be collected. Finally, a short analysis of minor wastes is also presented.

4.2.1. Coffee pulp (CoP)

The CoP has been included in diets for tilapia, Cachamay (*Colossoma*×*Piaractus*), common carp and African catfish reared in different systems resulting in variable growth responses. Fish reared in earthen ponds and receiving diets containing 300 g kg^{-1} of CoP (tilapia; Bayne et al., 1976) or up to 200 g kg^{-1} of CoP (Cachamay; Bautista et al., 1999) showed a similar growth as fish fed control or commercial diets. However, common carp (300 g kg^{-1} CoP diet) and African catfish (10–300 g kg^{-1} CoP diets) reared in aquaria and concrete tanks, respectively, showed a reduced growth

Table 8
Proximate composition (g kg^{-1}, DM) and energy content (kJ g^{-1}, DM) of several residues from animal origin. Data on proximate composition according to residue producers

Residues[a]	Component							
	Gross energy[b]	Energy for fish[c]	Crude ash	Crude fibre	Crude fat	NFE	Crude protein	Moisture (g kg^{-1})
Cattle–swine blood	≈23.2	14.2	29	≈5	≈5	≈5	956	796
Poultry manure[d]	14.6	6.7	193	282	20	323	183	160

[a] As defined in Table 1.
[b] Gross energy (kJ g^{-1}): protein (g kg^{-1})×23.87 + fat (g kg^{-1})×39.78 + NFE (g kg^{-1})×16.87 (DM basis).
[c] Potential digestible energy for fish, calculated according to digestible energy coefficients for *Ictalurus punctatus*, 14.6 kJ g^{-1} protein, 33.9 kJ g^{-1} fat and 10.5 kJ g^{-1} crude carbohydrate (N.R.C., 1977).
[d] Poultry manure was mainly from broiler production units and included bedding material. Its low moisture content (160 g kg^{-1}) was attributed to the "dry" condition of the manure when samples were collected from the production units.

and feed utilization (Christensen, 1981; Fagbenro and Arowosoge, 1991). Our results indicated that tilapia cultured in semi-intensive conditions can tolerate higher CoP inclusion levels (up to 130 g kg^{-1}) than in aquaria conditions (Ulloa and Verreth, 2003). These differences in growth and feed utilization may be related to CoP ANFs content, fish species and culture management practices. CoP has a relatively high contents of ANFs and fibre, and low protein and energy contents (Elías, 1979; Clifford and Ramírez, 1991, González et al., 1994).

Therefore, more research is needed to elucidate the feasibility of using CoP in fish diets, especially in diets for omnivorous species, including treatments to reduce its ANFs and fibre content. The low potential energy for fish (28% of gross energy) of CoP could limit its use in fish feeding. In addition, treatments to increase the digestible energy to fish, especially focusing on the reduction of the fibre and ANFs contents in CoP are advisable. For instance, CoP treated with *Bacillus* spp. showed a significant reduction on its fibre and ANFs contents, and additionally an increase in its protein content (Ulloa et al., 2003).

The drying and transportation costs are other factors that can also restrict the use of CoP in fish diets. However, many coffee processing units ("Beneficios") are located in very closed areas which could potentially reduced transportation costs.

4.2.2. Banana wastes

Green banana (GB) meal contains a high carbohydrate level (NFE ≈820 g kg^{-1}) and low levels of ash and fibre. It can also be considered as good energy source for fish diets because of its high energy content (≈17.8 kJ g^{-1}), especially in diets for omnivorous species. In addition, a high proportion of its gross energy (64%, 11.4 kJ g^{-1}) may potentially be digestible for fish. The tannin content in RGB may limit its use in fish feeds, however, the permissible level of RGB meal in fish diets can vary depending on fish specie and on the banana sources. The tannin content of RGB may vary depending on banana strains, plantation management and grade of ripeness. Our preliminary results have shown that RGB meal can be used in feeds for tilapia (*Oreochromis niloticus*) at levels lower than 300 g kg^{-1} without producing negative effects on growth and feed utilization (Segura and Ulloa, 2003).

The processing costs of drying and transportation are another factors that can restrict the use of RGB as ingredient in fish feeds. The banana plantations in Costa Rica are mainly located in the Atlantic region, which could reduce to some extend the transportation costs. Therefore, this could increase the feasibility to process RGB into banana meal and could also alleviate the RGB disposal problem.

From the other crop wastes reviewed in Costa Rica, oilpalm kernel and papaya meals have high gross energy and high potential digestible energy levels for fish. Oilpalm kernel meal is already used in animal feed manufacturing and it has been successfully tested in fish diets (Hossain and Jauncey, 1989). The amounts of papaya and other fruit wastes (especially orange and pineapple) have been progressively increasing during past 10 years, however, most of the processing plants are dispersed in many areas of the country; thereby, reducing their feasibility to be used as animal feedstuffs. Some other crop wastes, produced in Costa Rica in small amounts (e.g. cocoa husks and seed hulls), are produced in big amounts in others tropical countries and, therefore, they may be considered as possible fish feed ingredients. Cocoa wastes have a potential value as supplemental feed or in practical fish diets for tilapia, catfish and common carp (Fagbenro, 1988, 1992; Pouomogne et al., 1997). However, their inclusion in fish feeds are also limited by high fibre and moisture contents and the presence of ANFs.

5. Conclusion

Any attempt to use agricultural wastes will reduce their amount disposed of to the environment and, in return, produce extra benefits. Fishponds can be an alternative for using agricultural residues (Pullin, 1993). For instance, the inclusion of these low-graded wastes in fish feeds for species like tilapia and carp, which feed low in the food-web, may be an alternative method to reduce the agricultural waste disposal. However, the economical and environmental costs to use some of these agricultural wastes in fish feeds in Costa Rica have not yet been quantified to realize appropriate comparisons. These strategies have to be analyzed and applied in more general context, including not only the economical and production costs but also the rewards of reducing the environmental and social risks caused by the disposal methods used with most of the agricultural wastes.

Comparing data on residues (by-products and wastes) production from both agricultural production seasons analyzed in Costa Rica (1993–1994 and 2001–2002), it can be concluded that more effort is needed to: (a) increase the re-utilization of wastes in the different activities that already used them, (b) find new alternatives to utilize wastes that are disposed of into the environment. In the case of Costa Rica, in the past 10 years the use of coffee pulp has showed a relevant increment as also occurred with some wastes from cocoa, mainly as soil conditioners or fertilizer. However, ‘‘wastes burying in holes’’ is still the most common method of wastes disposal in Costa Rica.

In Costa Rica as in many other tropical countries, RGB and CoP constitute the most relevant wastes. Based on the criteria discussed above (e.g., nutritional composition, amount available and location), both wastes have potential as fish foodstuff, but CoP presents more ‘‘bottlenecks’’ (e.g., presence of polyphenols, tannins and caffeine) and, high fibre and K contents than RGB (Tables 9 and 10).

Despite its lower nutritional quality, CoP has already been studied in more detail than RGB for its use in fish feeds, as previously discussed. Because of the physicochemical differences between CoP and RGB, CoP poses a higher pollution risk than RGB. The CoP can loose about 260 g kg^{-1} of its wet weight (by evaporation and mainly drainage) during transportation (Vázquez, 1997) and about 50% of its weight in 5 min when it is immersed in aquatic environments (fine and loose particles and soluble components). In addition to its higher pollution risk, CoP contains higher levels of ANFs and cell wall components (cellulose, hemicellulose, neutral and acid detergent fibre) than RGB (Tables 9 and 10). Lignified protein (lignin binding–protein complexes), lignin and pectines are also largely present in CoP and may interfere with its use in fish feeds, since these components may reduce the feed digestibility. Consequently, utilization of CoP as a feed ingredient in fish diets asks for more research than RGB.

In banana and coffee producing countries, RGB and CoP are available in vast amounts without almost any restriction and they are nearly free of charge (depending on the amount required and producer country). Our findings may have an especial relevance in those regions where, in addition, omnivorous and/or herbivorous fish species such as *Oreochromis*, *Colossoma* and different carp species are cultured in extensive and/or semi-intensive systems. However, contrary to cereal by-products, the potential use of RGB and CoP in fish feeds will be constrained, to some extent, by its high moisture content. It must add the extra cost of drying to the production of their meals. Unfortunately, up to date there is not reported data estimating this cost at an industrial scale, which could allow a more precise cost comparison with other commercial feed ingredients of similar origin.

Other factor that can also restrict the use of these and other agricultural wastes in fish feeds are related to the

Table 9
Chemical composition of rejected green banana and coffee pulp meals (g kg^{-1}, DM)

Component	Green banana meal	Coffee pulp meal
Moisture (g kg^{-1})	808–881	767–850
Crude protein	31–59	80–148
Crude fat	14–58	12–49
Crude fibre	16–22	128–276
Crude ash	33–53	50–105
NFE	812–826	158–374
Cell wall constituents	[a]	314–556
C:N ratio	21.3	19.8–27.7

Sources: Elías (1979), Giorgetti and Ponzetta (1987), Bayne et al. (1976), Suntharalingam and Ravindran (1993) and own analysis.
[a] Not determined.

Table 10
Polysaccharides and ANFs characterization of coffee pulp and green banana meals (g kg^{-1}, DM)

Components	Green banana meal	Coffee pulp meal
Crude fibre	16	128–276
NDF	85–106	340–368
ADF	38–72	305–345
Cellulose	29–39	165–322
Hemicellulose	47–54	10–116
Pectines	[a]	60–65
Lignified protein	[a]	30
Lignin	9–10	122–205
Caffeine	0	5–20
Polyphenols	[b]	[b,c]
Caffeic acid	[a]	5–16
K	20–40	14–37

Sources: Murillo et al. (1976), Elías (1979), Giorgetti and Ponzetta (1987), Suntharalingam and Ravindran (1993), González et al. (1994), Pulgarin et al. (1991).
[a] Not determined.
[b] Tannins in banana meal (10 g kg^{-1}) and in CoP meal (14–86 g kg^{-1}).
[c] Chlorogenic acid: 26–34 g kg^{-1}.

content of toxic substances and pesticides in the wastes, which can accumulate in the fish (Pullin, 1993; Edwards, 1993). The dispersed location of most of these wastes (except for RGB and some CoP) may increase the costs of transportation, thereby reducing their economic feasibility to be recycled into fish feeds.

It is also recognized that further work is required to study the long-term effect, over a complete growing cycle in ponds, of feeding dietary RGB, CoP and other agricultural wastes on fish growth and feed utilization.

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References

AOAC (Association of Official Analytical Chemists), 1990. Official Methods of Analysis, fifteenth ed. AOAC, Virginia, USA.

Bautista, E., Useche, M., Pérez, F., Linares, F., 1999. Utilización de la pulpa de café ensilada y deshidratada en la alimentación de Cachamay (*Colossoma×Piaractus*). In: Ramírez, J. (Ed.), Pulpa de café ensilada. Producción, caracterización, y utilización en alimentación animal. Estado del Táchira, Venezuela, pp. 109–135.

Bayne, D., Dunseth, D., García, C., 1976. Supplemental feeds containing coffee pulp for rearing Tilapia in Central America. Aquaculture 7, 133–146.

Christensen, M., 1981. Preliminary tests on the suitability of coffee pulp in the diets of common carp (*Cyprinus carpio* L.) and catfish (*Clarias mossambicus* Peters). Aquaculture 25, 235–242.

Clifford, M., Ramírez, J., 1991. Phenols and Caffeine in wet-processed coffee beans and coffee pulp. Food Chemistry 40, 35–42.

Dean, J., Nielsen, L., Helfrich, L., Garling Jr., D., 1992. Replacing fish meal with seafood processing wastes in channel catfish diets. The Progressive Fish-Culturist 54, 7–13.

El Boushy, A., van der Poel, A., 1994. Poultry Feed from Waste. Processing and Use. Chapman & Hall, London, England.

Elías, L., 1979. Chemical composition of Coffee-berry by-products. In: Braham, J., Bressani, R. (Eds.), Coffee Pulp. Composition, Technology, and Utilization. Ottawa, Canada. pp. 11–16.

Edwards, P., 1993. Environmental issues in integrated agriculture-aquaculture and wastewater-fed fish culture systems. In: Pullin, R., Rosenthal, H., Maclean, J. (Eds.), Environment and Aquaculture in Developing Countries. ICLARM Conference Proceedings 31. Manila, Philippines. pp. 139–170.

Fagbenro, O., 1988. Evaluation of defatted cocoa cake as a direct feed in the monosex culture of *Tilapia guineensis* (Pisces: Cichlidae). Aquaculture 73, 201–206.

Fagbenro, O., Arowosoge, A., 1991. Growth response and nutrient digestibility by *Clarias isheriensis* (Sydenham, 1980) fed varying levels of dietary coffee pulp as replacement for maize in low-cost diets. Bioresource Technology 37, 253–258.

Fagbenro, O., 1992. Utilization of cocoa-pod husk in low-cost diets by the clariid catfish, *Clarias isheriensis* Sydenham. Aquaculture and Fisheries Management 23, 175–182.

Giorgetti, A., Ponzetta, M., 1987. I sottoprodotti della coltivazione del banano nell'alimentazione dei ruminanti. Rivista di Agricoltura Subtropicale e Tropicale 81, 429–443.

González, N., Ramírez, J., Aldana, J., Clifford, M., 1994. Analysis of proanthocyanidins in coffee pulp. Journal of the Science of Food and Agriculture 65, 157–162.

Hossain, M., Jauncey, K., 1989. Nutritional evaluation of some Bangladeshi oilseed meals as partial substitutes for fish meal in the diet of common carp, Cyprinus carpio L. Aquaculture and Fisheries Management 20, 255–268.

Krogdahl, A., 1989. Alternative protein sources from plants contain antinutrients affecting digestion in salmonids. In: Takeda M., Watanabe, T. (Eds.), Proceeding of the Third International Symp. on Feeding and Nutrition in Fish. Toba, Japan. pp. 253–261.

Li, H., Manning, B., Robinson, E., 2002. Comparison of various animal protein sources for growth, feed efficiency, and body composition of juvenile channel catfish *Ictalurus punctatus*. Journal of World Aquaculture Society 33, 489–493.

López, E., Pabón, M., 1986. Mejoramiento nutricional de la pulpa de café. Noticias Químicas 42, 23–36.

Moon, H., Gatlin III, D., 1994. Effects of dietary proteins on growth and body composition of the red drum (*Sciaenops ocellatus*). Aquaculture 120, 327–340.

Mueller-Harvey, I., McAllan, A., 1992. Tannins. Their biochemistry and nutritional properties. Advances in Plant Cell Biochemistry and Biotechnology 1, 151–217.

Murillo, B., Daqui, L., Cabezas, M., Bressani, R., 1976. Pulpa y pergamino de café. XI. Características químicas de la pulpa de café, ensilada con pasto Napier (*Pennisetum purpureum*) y la planta de maíz (*Zea mays*). Archivos Latinoamericanos de Nutrición 26, 33–45.

N.R.C. (National Research Council), 1977. Nutrient Requirement of Warmwater Fishes. National Academy of Science, Washington, DC, USA.

Osborne, D., Voogt, P., 1986. Análisis de los nutrientes de los alimentos. Editorial Acribia, SA, Zaragoza, España.

Pouomogne, V., Takam, G., Pouemegne, J., 1997. A preliminary evaluation of cacao husks in practical diets for juvenile Nile tilapia (*Oreochromis niloticus*). Aquaculture 156, 211–219.

Pulgarin, C., Schwitzguebel, J., Tabacchi, R., 1991. Comment blanchir les résidus du café noir? Biofutur 102, 43–50.

Pullin, R., 1993. An overview of environmental issues in developing-country aquaculture. In: Pullin, R., Rosenthal, H., Maclean, J. (eds.), Environment and Aquaculture in Developing Countries. ICLARM Conference Proceedings 31. Manila, Philippines. pp. 1–19.

Rathbone, C., Babitt, J., Dong, F., Hardy, R., 2001. Performance of juvenile Coho Salmon Oncorhyncus kisutch fed diets containing meals from fish wastes, deboned fish wastes, or skin-and-bone by-products as the protein ingredient. Journal of the World Aquaculture Society 32, 21–29.

Ravishankar, A., Keshavanath, P., 1986. Growth response of Macrobrachium rosenbergii (de Man) fed on four pelleted feeds. Indian Journal of Animal Sciences 56, 110–115.

Segura, R., Ulloa, J., 2003. Growth and diet digestibility of tilapia *Oreochromis niloticus* fingerlings fed practical diets containing graded levels of green banana meal. In: Word Aquaculture Society (ed.), Book of Abstracts of Word Aquaculture 2003. Salvador, Brazil.

Sehgal, H., Sharma, S., 1991. Efficacy of two new supplementary diets for an Indian major carp, *Cirrhina mrigala*: effects on flesh composition. Journal of the Aquaculture in the Tropics 6, 25–34.

Sehgal, H., Sharma, S., 1993. A note on evaluation of some wastes and by-products from agriculture and animal husbandry as feed ingredients for *Cirrhina mrigala* (Ham.). Bioresource Technology 44, 9–11.

Subosa, P., 1992. Chicken manure, rice hulls, and sugar-mill wastes as

potential organic fertilizers in shrimp (*Penaeus monodom* Fabricius) ponds. Aquaculture 102, 95–103.
Suntharalingam, S., Ravindran, G., 1993. Physical and biochemical properties of green banana flour. Plant Food and Human Nutrition 43, 19–27.
Tacon, A., 1993. Feed ingredients for warmwater fish: fish meal and other processed feedstuffs. FAO Fisheries Circular No. 856. Rome, Italy.
Tacon, A., 1994. Feed ingredients for carnivorous fish species: alternatives to fish meal and other fishery resources. FAO Fisheries Circular No. 881. Rome, Italy.
Ulloa, J., 1997. The major agricultural wastes and by-products and their potential use in fish culture: a case study in Costa Rica. In: Durán, M., Moya, M., Vega, J., Sibaja, R., Pereira, R., Nikolaev, S. (eds.), Resumenes I Congreso Iberoamericano de aprovechamiento de desechos y tecnologías limpias. San José, Costa Rica. pp. 30.
Ulloa, J., Verreth, J., 2003. Growth of *Oreochromis aureus* fed with diets containing graded levels of coffee pulp and reared in two culture systems. Aquaculture 217, 275–283.
Ulloa, J., Verreth, J., Amato, S., Huisman, E., 2003. Biological treatments affect the chemical composition of coffee pulp. Bioresource Technology 89, 267–274.
Vázquez, R. 1997. El beneficiado ecológico del café. In: Echeverri, J., Zamora, L. (eds.), Memorias XVIII Simposio Latinoamericano de Caficultura. San José, Costa Rica. pp. 51–64.
Watson, N., 1985. Processed piggery waste as a feed material for *Cyprinus carpio*. Aquaculture 44, 167–176.
Webster, C., Tiu, L., Morgan, A., Gannam, A., 1999. Effect of partial and total replacement of fish meal on growth and body composition of Sunshine Bass *Morone chrysops* × *M. saxatilis* fed practical diets. Journal of the World Aquaculture Society 30, 443–453.
Wohlfarth, G., Hulata, G., 1987. Use of manures in aquaculture. In: Moriarty, D., Pullin, R. (Eds.), Detritus and Microbiological Ecology in Aquaculture. ICLARM Conference Proceeding 14. Manila, Phillipines. pp. 353–367.