Potential Use of Agricultural Wastes in Aquafeed Production

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Abstract

Disposal of agricultural wastes are posing environmental hazards which leads to efforts of efficiently utilizing them. This study surveyed a sugar central and a fruit processing plant to collect data on the volume of wastes from representative agricultural crops (e.g. mango, citrus, pineapple, sugarcane, papaya and soybean) in the Philippines during the 2012–2013 and 2014–2015 seasons, respectively. Their potential use in aquafeed was examined in terms of nutritional quality, presence of anti-nutritional factors (ANFs) and pesticide residues. About 40 to 60 % of agricultural wastes generated after processing were peels, pulps or brans, seeds, bagasse, molasses and okara. Most of the agricultural wastes had high levels of fiber and carbohydrate, and low levels of protein, although okara (25 % crude protein) and citrus by-products (11–16 % crude protein) showed acceptable nutritional quality. ANFs such as lignin are largely present in all agricultural wastes, whereas high levels of phenols, and saponins and alkaloids were found in mango seeds and mango peels, respectively. Pesticide residues were detected only in mango and citrus peels but at levels below the maximum residue limits of FAO Codex Alimentarius. From both nutritional and environmental perspectives, agricultural wastes have potential use in aquafeed production but their suitability should be further elucidated in diets for omnivorous fish species such as tilapia.

Keywords: agricultural wastes; anti-nutritional factors; pesticide residues

Introduction

The increasing growth of the aquaculture sector has undeniably intensified the demand for compound feeds. The projected feed usage of major fed species in 2020 amounted to 65.4 million metric tons (Tacon and Metian, 2015). Commercial feeds are expensive for the smallholder farmers, mainly attributed to fishmeal (FM) and fish oil (FO), which are included at higher proportions. Therefore, focusing on readily available alternative feed sources which could provide affordable options in feed formulation is necessary.

The Philippines has 13 million hectares dedicated to farming of agricultural crops such as mango, coconut, banana, pineapple, citrus and sugarcane. Tremendous amounts of agricultural wastes are produced after the processing of these crops that could be utilized for animal feed production. The most common wastes include peels, seeds, pulps or bran, bagasse, and molasses. However, limited information is available on the availability and utilization of these agricultural wastes in the aquaculture industry. Disposal of these agricultural wastes may cause adverse environmental impacts. Efforts to efficiently utilize them as raw material for aquafeed production would be beneficial for the development of the feed industry (Aya, 2017).

Some agricultural wastes have been successfully utilized in diets for Pacific white shrimp *Litopenaeus vannamei* (Forster *et al*., 2010), Nile tilapia *Oreochromis niloticus* (El-Sayed, 1991; Akegbejo-Samsons *et al*. 2006; El-Sayed *et al*., 2010; El-Saidy, 2011) and rohu *Labeo rohita* (Abani Deka *et al*., 2003). The suitability of agricultural wastes in fish feeding would depend on their nutritional composition, presence of anti-nutritional factors (ANFs), and food safety issues such as pesticide residues. While these factors may limit higher inclusion of agricultural wastes in aquafeed, appropriate processing techniques may be employed to improve their nutritional value and to reduce their ANFs contents.

To ascertain the potential use of representative agricultural wastes in aquafeeds, this study surveyed a sugar central and a fruit processing plant to collect data on the volume of agricultural wastes produced during the 2012–2013 and 2014–2015 seasons, respectively. Interviews were also conducted at relevant government agencies to gather information on agricultural waste management and utilization projects in the aquaculture sector. The proximate composition, presence of ANFs and pesticide residue levels were also examined to determine the suitability of agricultural wastes in aquafeed production for environmental and economic reasons.

Materials and methods

A review of secondary data, interviews and visits to the government offices (e.g. Philippine Statistics Authority, Bureau of Plant Industry, Sugarcane Regulatory Administration and the Bureau of Agricultural Research), sugar central (Balayan, Batangas, Philippines) and fruit processing plant (Guiguinto, Bulacan, Philippines) were conducted to obtain relevant data and information on the 1) production statistics of major agricultural crops; and 2) volume of waste production, utilization and treatment. The volume of agricultural wastes produced from sugarcane industry covered the 2012-2013 season, whereas those from the fruit processing plant were obtained during the 2014-2015 production season.

Agricultural wastes (e.g. sugarcane baggase, mango peel and kernel, citrus peel, pulp and seeds) were collected directly from their respective processing plants. Okara (a soy byproduct), banana and pineapple peels were obtained from cottage industries and wet market, respectively in Binangonan, Rizal, Philippines and transported to the SEAFDEC/AQD laboratory, also in Binangonan, for further processing. Agricultural wastes were rinsed or washed (when appropriate), oven-dried at 60°C, ground and stored for further analysis. The proximate composition (crude protein, crude fat, crude fiber, crude ash and moisture) was determined using standard methods (AOAC, 2000). They were also examined for the presence of anti-nutritional factors (ANFs; e.g. tannin, phenol, saponin, lignin and alkaloid) and pesticide residues (e.g. organochlorines, pyrethroids and organophosphates). Samples for the analyses of ANFs and pesticide residues were submitted to the Philippines' Adamson University Technology Research and Development Center and the Department of Agriculture - Bureau of Plant Industry National Pesticide Analytical Laboratory, respectively.

Results

Agricultural wastes and their utilization

Table 1 shows the volume of production among major agricultural crops in the Philippines. Sugarcane registered the highest volume of production, followed by coconut, banana, pineapple, mango and citrus. The estimated quantity of wastes generated from the major crop industries (e.g. mango, pineapple, citrus and sugarcane) after processing are presented in **Table 2**, including that of okara.

Table 1. Volume of production of agricultural crops in the Philippines, 2013[1]

Crops	Production (in MT)[1]
Sugarcane	24,584,820
Coconut	15,344,000
Banana	8,645,749
Pineapple	2,458,422
Mango	816,199
Citrus	164,060
Soybean[2]	1.5-2.5

[1]Philippine Statistics Authority 2014
[2]Data accessed from http://businessdiary.com.ph/4551/soybean-production-guide/; production from NW and Central Luzon and Surigao del Sur; unit expressed as t/ha

Table 2. Volume of production and wastes among major agricultural crops in the Philippines, 2013

Crops	Volume use in production (in tons)	Volume of wastes produced (in tons)	Type of Wastes
Mango[1]	3,600-4,800	1,800-2,400	peel, kernel, seeds
Calamansi[1]	2,700-3,150	1,755-2,047	peel, seeds, pulp
Pineapple[1]	210	105-126	bran, peels
Sugarcane[2,3]	24,859,027	9,175,010	bagasse, filter cake,
	470,229	172,544	Molasses
Papaya[1]	60	30-36	pomace, seeds
Soybean[4]	1.5	1.5	okara

[1]Data obtained from a Fruit Processing Plant in Guiguinto, Bulacan
[2]SRA Annual Synopsis: Philippine Sugar Factories' Production and Performance Data 2012-2013
[3]Data obtained from a Sugar Central in Balayan, Batangas
[4]Data obtained from cottage industries in Binangonan, Rizal

Nutrient composition of agricultural wastes

The proximate composition of agricultural wastes is shown in **Table 3**. The moisture content ranged from 1.38 % to 8.09 %. The highest protein content was found in okara (25.31 %) followed by citrus by-products (9.28 %–15.71 %) and the lowest protein content was found in sugarcane bagasse (2.83 %) and mango kernel (2.53 %). Citrus seeds had the highest fat content followed by okara and banana peel. Except for mango kernel, sugarcane bagasse, okara and fruit wastes had the highest fiber levels. The highest NFE was determined in mango (78.06 % to 88.34 %) and pineapple (81.41 %) wastes and the highest ash content in banana peel (14.81). The highest gross energy content was estimated in citrus seeds (23 kJ g^{-1}) followed by okara (18.77 kJ g^{-1}) and other fruit wastes (14.11 to 16.68 kJ g^{-1}). The lowest gross energy content was determined in sugarcane bagasse (10.20 kJ g^{-1}). The potential digestible energy for fish also showed the same trend as gross energy.

All agricultural wastes contained ANFs (e.g. tannin, phenols, saponin, lignin and alkaloid) (**Table 4**). Citrus seeds and mango kernel had the highest tannin levels (0.28 and 0.29 %) whereas okara and pineapple peel had the lowest at 0.11 %. Okara and citrus seeds were detected to contain saponin levels at 0.25 and 0.09 %, respectively. All contained high levels of lignin particularly citrus seeds (47.45 %). Mango kernel was characterized by a high level of phenol (11.31 %) and alkaloid (3.90 %).

Pesticide residues

Among the agricultural wastes analyzed, mango peel and citrus peel were found to contain pesticide residues (**Table 5**). Lamba-cyhalothrin, an insecticide which belongs to a group of chemicals called pyrethroids, was found in mango peels at 0.14 mg/kg. Another insecticide, chlorpyrifos was detected in citrus peels at 0.04 mg/kg.

Discussion

Agricultural wastes are the materials left after the production and processing of agricultural products (Obi *et al*., 2016). In the Philippines, many of these agricultural wastes were not utilized and their treatment and disposal can be costly. The huge amount (about 40–60 %) of wastes from agricultural crops, as surveyed in this study albeit from a very limited sources, suggest that available source of alternative feed sources is not a problem. Most of these agricultural wastes have varied industry uses such as in the development of functional feed ingredient or high-value products using biotechnological approaches, organic fertilizers, or as supplemental feeds or feedstuffs in the animal (e.g. livestock and poultry) feeds. Converting these wastes into potential feed ingredients for fish culture can also provide additional benefits to its utilization. However, several factors such as the nutritional aspects, including the presence of anti-nutritional factors (ANFs) and levels of pesticide residues shall be considered to evaluate their suitability in aquafeed production.

The agricultural wastes analyzed in this study generally contain low levels of protein and high levels of carbohydrate (as nitrogen free extract) and fiber. Only okara have the highest acceptable crude protein content (25 %) suggesting its potential use as a protein source, followed by citrus by-products which contain 9 to 11 % crude protein. High lipid contents found in citrus seeds, okara and banana peels suggest that these wastes could be an alternative sources of quality plant lipids. Extraction

Table 3 . Proximate composition (% dry matter) and energy content for fish (kJ g^{-1}) of some representative agricultural wastes in the Philippines, 2013

Agricultural wastes	Moisture	Crude Protein	Crude Fat	Crude Fiber	NFE[1]	Ash	Gross energy[2]	Potential digestible energy for fish[3]
Sugarcane bagasse	6.27	2.83	0.46	33.90	55.39	7.43	10.20	6.39
Pineapple peel	6.28	4.27	0.61	9.53	81.41	4.19	15.00	9.38
Banana peel	3.19	6.44	7.41	8.02	63.33	14.81	15.17	10.10
Citrus pulp	8.09	9.28	1.30	16.00	67.32	6.11	14.09	8.86
Citrus peel	7.59	11.50	0.72	13.90	65.69	8.20	14.11	8.82
Citrus seed	1.38	15.71	31.49	8.33	39.83	4.64	23.00	17.15
Citrus, whole	2.90	11.22	2.91	10.67	69.70	5.51	15.59	9.94
Mango peel	6.25	5.93	2.15	10.95	78.06	2.93	15.44	9.79
Mango kernel	5.19	2.53	2.94	3.65	88.34	2.55	16.68	10.64
Okara meal	4.54	25.31	12.85	12.99	45.14	3.72	18.77	12.79

[1]NFE, Nitrogen Free-Extract

[2]Gross energy (kJ g^{-1}) was calculated using standard physiological values of 23.87, 39.78, and 16.87 for protein, lipid and carbohydrate, respectively (Ulloa, 2002)

[3]Potential digestible energy for fish (kJ g^{-1}) was calculated according to digestible energy coefficients of 14.6, 33.9, and 10.5 for protein, lipid and carbohydrate, respectively for channel catfish (NRC, 1977)

Table 4. Anti-nutritional factors (ANFs) present in some representative agricultural wastes in the Philippines, 2013

Agricultural wastes	ANFs (%)				
	Tannin	Phenols	Saponin	Lignin	Alkaloid
Sugarcane baggase	0.20	1.93	-	41.49	0.71
Pineapple peel	0.11	0.53	-	21.39	0.16
Banana peel	0.20	0.39	-	41.11	0.36
Citrus seeds	0.29	0.66	0.09	47.45	1.10
Citrus peel	0.20	0.71	-	31.97	0.61
Citrus pulp	0.18	0.71	-	24.94	0.15
Mango peel	0.61	ND*	3.00	29.00	16.00
Mango kernel	0.28	11.31	-	15.42	3.90
Okara	0.11	0.60	0.25	41.49	0.11

*ND, not detected

Table 5. Pesticide residue levels in some representative agricultural wastes in the Philippines, 2013

Agricultural wastes	Pesticide residue (mg/kg)*		
	Organochlorines	Pyrethroids	Organophosphates
Sugarcane baggase	< LOQ	< LOQ	< LOQ
Pineapple peels	< LOQ	< LOQ	< LOQ
Mango peels	< LOQ	Lamba-cyhalothrin = 0.14	< LOQ
Banana peels	< LOQ	< LOQ	< LOQ
Citrus peels	Chlorpyrifos = 0.04	< LOQ	< LOQ

*Limit of Quantification (LOQ) for organophosphates, organochlorines and pyrethroids is 0.01 mg/kg

of lipids from these wastes using organic solvents could further increase their nutritional quality. All except for mango seed or kernel have higher levels of crude fiber (8-34 %) exceeding the requirement (less than 7 %) in aquafeeds, thereby limiting the utilization of this ingredient. Fiber contents in aquafeeds should be maintained at less than 7 % to reduce the amount of undigested material going into the receiving waters (Gatlin, 2010). High ash content found in banana peels (more than 12 %) could result to poor digestibility and growth of fish when promoted in aquafeeds (De Silva and Anderson, 1995).

The presence of anti-nutritional factors (ANFs) in alternative feed sources is another factor that could limit their utilization in aquafeeds (Francis *et al*., 2001). All the agricultural wastes in the present study showed the presence tannins, phenols, saponins, lignin and alkaloids. Tannin contents (0.11-0.29 %) did not exceed the 0.63% level known to cause an impact on the digestibility of dry matter, protein and lipid (Pinto *et al*., 2000). In another study, tannins at 2 % inclusion rate in the diet could interfere with the digestive processes (Becker and Makkar, 1999). All the agricultural wastes had levels of tannins below this inclusion rate. Agricultural wastes had high levels of lignin (15.42–47.45 %) which may affect protein digestibility and palatability. High levels of phenol in mango seed (11.31 %) may limit its use in fish feeding given that long-term exposure of phenols above this inclusion rate (0.002 %) have negative effect on the immune response of *Tilapia nilotica* fingerlings (Zaki and Fawzi, 2016). Saponin, which gives a bitter taste that can reduce palatability in fish diets, was found in low levels in citrus seeds (0.09 %), and are unlikely to affect fish growth due to their lower contents (Francis *et al*., 2001). High levels of saponin found in mango peels (3 %) and intermediate in okara (0.25 %), and their inclusion at higher levels in fish diets may result in low feed palatability and utilization (Tacon, 1993). Saponins above 0.15 % inclusion rate was detrimental to the growth and intestinal morphology in fish (Francis *et al*., 2001), and both okara and mango peels exceeded this level. Despite this high saponin contents, mango peels could still be considered a potential feed ingredient as they contain a concentrated amount of carotenoid pigments that are contributors to fish reproduction. Therefore, to reduce the ANF contents and maximize the inclusion in fish diets, these agricultural wastes should be processed further using biological or chemical techniques (e.g. ensiling or solid state fermentation).

Apart from their nutritional quality, pesticide residues in agricultural wastes should be examined before finally considering them in fish feeds. Pesticide residues such as lamba-cyhalothrin and chlorpyrifos were detected in mango and citrus peels, respectively, and residue levels were found to exceed the limit of quantification of the Philippines' Department of Agriculture - Bureau of Plant Industry National Pesticide Analytical Laboratory. Lamba-cyhalothrin is an insecticide which belongs to a group of chemicals called pyrethroids, and chlorpyrifos is also an insecticide. However, the detected pesticide residue levels were still lower than the maximum residue limits (MRLs) adopted by the FAO Codex Alimentarius for mango (0.2 mg/kg) and citrus (1 mg/kg) in 2009 and 2013, respectively (http://www.fao.org/fao-who-codexalimentarius/codex-texts/maximum-residue-limits/en/). This show that the use of mango and citrus peels may not pose any adverse impact on fish health condition when promoted in aquafeed production although further studies are needed.

Okara have already been used as a protein source replacing fishmeal at levels up to 750 g kg^{-1} in mono-sex Nile tilapia fingerlings diets (El-Saidy, 2011). In contrast, our results showed that okara have been included in mixed-sex Nile tilapia fingerlings at levels up to 300 g kg^{-1} diet (Aya *et al*., unpublished data). The low inclusion levels of okara in our study may be due to high fiber content and the presence of ANFs in this ingredient.

Conclusion

Agricultural wastes have very low or no commercial value, and are readily available in large quantities, making them potential feed ingredients in aquafeeds. The suitability of these agricultural wastes was evaluated based on nutritional composition, presence of anti-nutritional factors (ANFs) and pesticide residues. Because most agricultural wastes contain ANFs and high fiber content, appropriate processing treatments to increase their nutritional value should be applied and their suitability tested in diets for omnivorous fish species such as tilapia to promote low-cost feeds for fish culture.

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